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Development of a Simplified Programming Kit Based 16LF18856 for Embedded Systems Testing and Education in Developing Countries

Jean de Dieu Nguimfack-Ndongmo[1,6] · Kevin Kentsa Zana[2] · Derek Ajesam Asoh[1,3,4] · Nicole Adélaïde Kengnou Telem[5] · René Kuate-Fochie[6] · Godpromesse Kenné[6]

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Abstract

Embedded systems and applications have recently emerged as a domain of high interest to the general public in developing countries. Unfortunately, these countries lack the technological infrastructure for the design, testing, and implementation of projects in the domain. This paper presents a Very Simple Programming Kit (VSPK) for Embedded Systems suitable for practical training, project design, and testing in the domain for use in developing countries. The microcontroller-based system makes it easy to test, teach and train in various areas of embedded systems including programming, communication, signal acquisition and processing, remote control, and domotics. A VSPK prototype has been produced and is used for real-time simulation of Embedded applications. This operation involves the VSPK, the PIC programmer, the PC and the application program to be tested progressively and the displays observed on the LCD and LEDs. The debugging process is easily performed and errors are detected and corrected. The main features of VSPK are low production cost, low power consumption, flexible peripheral pin selection, integrated LCD module, and simple hardware and software environment. Unlike similar kits available for educational purposes, VSPK possesses some advantages such as an integrated graphic color LCD, a configurable internal oscillator, numerically controlled oscillators, testing LEDs, testing buttons, and complete access to multiple programming languages. Two experimental and simple tests for validation of VSPK have been carried out, and the results show that VSPK performs satisfactorily.

Keywords Embedded systems · Microcontroller programming · Testing · Education · Sub-Saharan Africa

Responsible Editor: V. D. Agrawal

✉ Jean de Dieu Nguimfack-Ndongmo
nguimfack.jean@uniba.cm

Kevin Kentsa Zana
kevitronix@gmail.com

Derek Ajesam Asoh
derekasoh@uniba.cm

Nicole Adélaïde Kengnou Telem
kengnou.adelaidenicole@ubuea.cm

René Kuate-Fochie
rene.kuate@univ-dschang.org

Godpromesse Kenné
godpromesse.kenne@univ-dschang.org

1 Department of Electrical and Power Engineering, Higher Technical Teacher Training College, University of Bamenda, Bambili, Bamenda 39, North-West, Cameroon

2 Département du Génie des Procédés, ENSET de Douala, Université de Douala, Ndogbong, Douala 1872, Littoral, Cameroun

3 Laboratoire de Génie Électrique, Mécatronique et Traitement du Signal, ENSPY, Université de Yaoundé I, Ngoa-Ekelle, Yaoundé 337, Centre, Cameroun

4 Department of Electrical and Electronic Engineering, NAHPI, University of Bamenda, Bambili, Bamenda 39, North-West, Cameroon

5 Department of Electrical and Electronic Engineering, College of Technology, University of Buea, Molyko, Buea 63, South-West, Cameroon

6 Unité de Recherche d'Automatique et d'Informatique Appliquée (UR-AIA), Département de Génie Électrique, IUT FOTSO Victor, Université de Dschang, Nkoung-Khi, Bandjoun 134, Ouest, Cameroun

1 Introduction

As electronic research is growing in the modern world, embedded systems (ES) are becoming more interesting to the general public and especially to computer, electrical, and electronic engineers who can design and build a wide variety of systems, such as robots, automated systems, signal processing systems, etc. There are numerous advantages of using embedded systems kits in design and testing. Designers can ensure the performance of necessary tasks for a wide range of applications with less cost than building personalized solutions. This is rightly true for devices that will be produced in large numbers. Choosing an embedded system rather than acquiring discrete components and spending time designing and building a device to perform the equivalent task can save significant time and financial resources. Embedded modules are also reliable and easy to incorporate into other devices. Classical examples of devices with ES include smartphones, tablets, digital cameras, TV setup devices, automotive control devices, traffic control, security systems, domotic systems, personal robots, and biomedical equipment [18, 19].

Many Technology Colleges offer introductory courses on microcontroller-based modules and embedded systems programming using various training kits to design and test the prototypes. Most of these kits are useful for training in several domains, namely: programming language, digital system (hardware descriptive language), and basic signal/image processing [8]. A significant number of ES kits with built-in systems based on the intensive utilization of software are now available online and can not be purchased by students interested in the field. Among these kits, we can name a few, such as Rapid Embedded Systems Design Education Kit (RESDEK) [2]; 8051 Embedded Distance Learning Kit (7EDLK), Arduino Mega 2560R3 Board (AMB) based on ATmega2560 microcontroller and Velleman kit (USB VM112-K8055). The RESDEK program covers the main principles necessary to improve the development of ES and rapidly prototype various ES applications. Its aim is to train students who can design, build and program Arm-based ES using commercial application programming interfaces (API) [5]. The 7EDLK is a program for students to learn 8051 ES from the basics through distance education in seven days [17]. Some ES projects involve application platforms, such as the Open Platform for Engineering of Embedded Systems (OPEES) which are available online to ease access to universal approaches in creative learning environments and information management [14, 15]. The objective of OPEES is to offer a long-term availability of innovative engineering tools and real-time solutions for ES that are suitable for domotic, emergency, and security systems [7]. But most of those applications, including supporting e-services, require network connectivity, display support, and graphic or video capabilities. Unfortunately, these requirements are not easily met in developing countries [13]. Therefore, the motivation of this work is to develop a low-cost embedded system for educational purposes that is well-suited to developing countries, where access to networks and other equipment is not always possible. The main objectives of this paper among others are: to design, build, and present a testing and educational Kit named Very Simple Programming Kit (VSPK) for embedded systems off-line; To motivate students to learn about design, implementation, programming, and testing of embedded systems using the proposed low-cost kit. The kit has low power requirements, a flexible peripheral pin selection, and an integrated color LCD and provides a friendly hardware/software environment adapted for developing countries such as those in Sub-Saharan Africa.

1.1 Main Contributions

- A new electronic kit suitable for embedded systems design and testing has been developed.
- This tool is useful for pedagogic purposed and cost-effective for students in developing countries to learn more about the design, implementation, programming, and testing of embedded systems.
- The kit has low power requirements, a flexible peripheral pin selection, an integrated color LCD and provides a friendly hardware/software environment
- VSPK is multiple language-compatible: MicroPascal, MicroBasic, and various C compilers.

1.2 Structure of the Paper

The paper is organized into seven sections: structure and design of the proposed kit in section 2, prototype execution and main features of VSPK in section 3, comparative study of VSPK and Arduino Uno Board in section 4, embedded systems courses overview and challenges in section 5, experimental setup and testing with VSPK in section 6, economic evaluation of the cost in section 7 and a conclusion, in which we provide some remarks on VSPK and directions for future work in section 8.

2 Structure and Design Process of the Proposed Kit

The various components, passive, active, and integrated were chosen through a methodical process involving electronic calculations, application notes from manufacturers, reference designs, environmental parameters (temperature) and electrical parameters (voltage, current, power, accuracy response time) [12]. Application notes from the

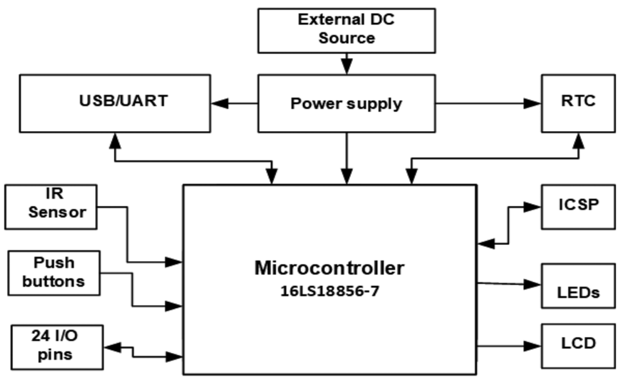


Fig. 1 Block diagram of the proposed kit

manufacturer helped a lot in understanding the functioning of a circuit and many times tested electronic components rating was also provided, which reduces design errors. Some manufacturers have also provided a lot of other resources like industry-specific reference design, and software tools to help us to evaluate the performance of the electronic component as per our own configurations before even designing anything. This heavily reduced the development time and chances of failure.

The block diagram of VSPK is shown in Fig. 1 and consists of microcontroller 16LF18856 and peripheral units which are USB (Universal Serial Bus)/UART (Universal Asynchronous Receiver transmitter)link & PC connection, ICSP (In-Circuit Serial Programming) link for PIC Programmer and Inter-Integrated Circuit (I2C) communication port.

Interfacing the various components of the kit by taking into consideration all the specifications and possible constraints was the greater challenge in the design process. Therefore, the application notes of these components were consulted and exploited to design and build a functioning device with good performance.

The electronic diagram of the proposed system is shown in Fig. 2.

2.1 Microcontroller and Selection Criteria

The 8-bit microcontroller 16LF18856 has been selected for the proposed kit, based on three considerations: first, its low cost compared to 32-bit controllers; second, availability in the local market and suitability for small-scale applications especially for educational purposes in developing countries; and third, pertinent relevant features presented in its datasheet; such as a configurable internal oscillator, low voltage supply (1.8V to 3.6V) and low power (800mW) compared to (2.3V to 5.5V) and (1000mW) of PIC16F18856, respectively.

Some electrical specifications of 16LF18856 are quite interesting for embedded systems design [11]:

- Voltage on pins with respect to Vss: on V_{DD} pin $(-0.3V\ to + 4.0V)$, on Vpp/MCLR pin $(-0.3V\ to + 9.0V)$, on all other pins $(-0.3V\ to\ V_{DD} + 0.3V)$
- Maximum current on V_{DD} pin: 250 mA when the ambient temperature (TA) is $-40\,℃ < TA < +85\,℃$
- Maximum current on any standard I/O pin: $\pm 20mA$

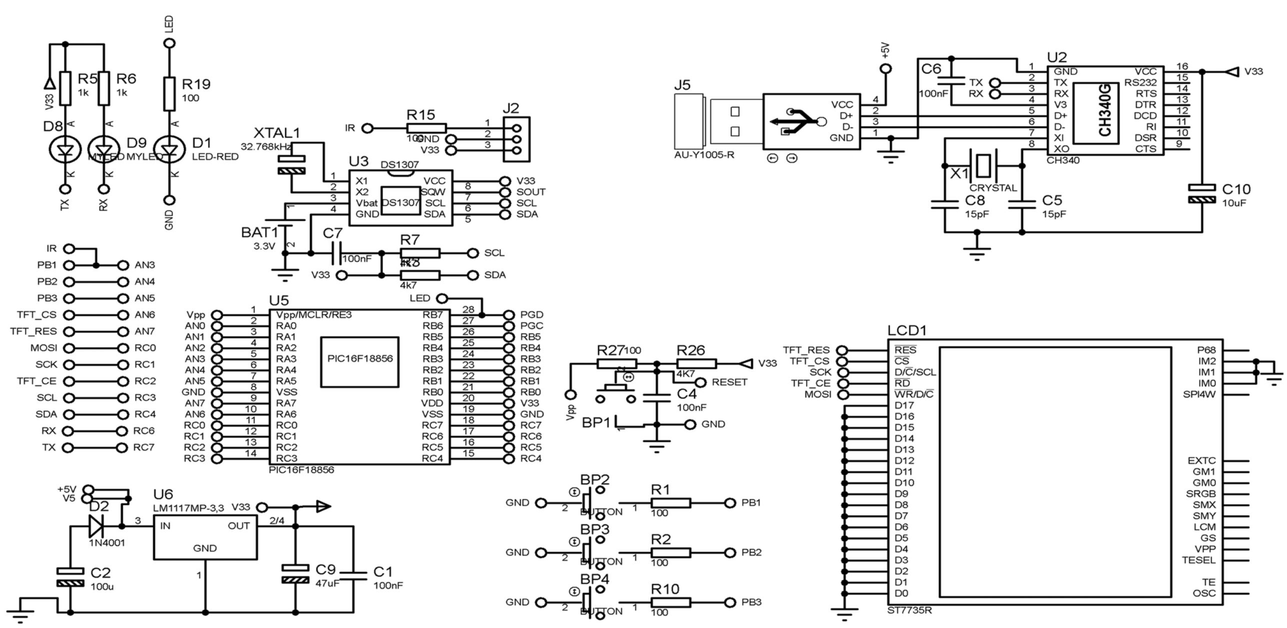


Fig. 2 Electronic diagram of the proposed kit

- Total power dissipation (P_{DIS}) which is 800 mW is calculated as follows [11]:

$$P_{DIS} = V_{DD}[I_{DD} - \sum I_{OH}] + \sum[(V_{DD} - V_{OH})I_{OH}] + \sum V_{OI}I_{OL} \quad (1)$$

where I_{DD} is the supplying current, I_{OH} the current of an output pin at the higher level voltage, I_{OL} the current of an output pin at the lower level voltage, V_{OH} the higher level voltage of an output pin, and V_{OL} the lower level voltage of an output pin.

This 8-bit microcontroller is part of the PIC(L)F1885X/7X family characterized by core independent and communication peripherals, combined with eXtreme Low-Power (XLP) technology for a wide range of general purpose and low-power applications [11]. This family is suitable for safety-critical applications targeting both industrial and automotive products (IEC61508 and ISO26262 [11]) such as the proposed kit. The 16LF18856 is equipped with three 8-bit timers, and four 16-bit timers (7 timers in all). It is equipped with a good capacity memory: 256 bytes-EEPROM, 2kB-SRAM, 28kB-Flash memory; with interrupt capabilities (all pins have configurable interrupts on rising and falling edges); multiple signal sources; five Capture/Compare/PWM (CCP) modules, two 10-bit PWMs; and a Numerically Controlled Oscillator (NCO). The controller can generate true linear frequencies with high resolution. Other interesting features of microcontroller 16LF18856 are found in the datasheet [11].

2.2 Interfacing USB/UART Link & Computer Connection

The USB link has an onboard connector and four pins. Two pins for power supply (5V and ground) and two for data communication (D+ and D-). The USB to UART interface is realized using the CH340G circuit. This circuit is essentially a USB adapter that is used not only to provide common modem signals but also to allow adding UART devices to computers and/or convert existing UART devices to USB interfaces [1]. Use of the CH340G circuits entails the installation of a USB-UART driver such as CH341SER for PC connectivity. The USB/UART subsystem is built around the CH340G integrated circuit as shown in Fig. 2. During operation, CH340G requires a clock signal. This clock signal is provided by connecting a crystal oscillator and load capacitance between X0 and X1 pins. The load capacitance is the circuit equivalent capacitance looking at the circuit system from the two wire leads of crystal. This is the capacitance the crystal will see in the circuit and operate at the specified frequency. Therefore, the operation frequency in the circuit is defined by load capacitance and crystal

$$C_L = \frac{C_5 C_8}{C_5 + C_8} + C_{stray} \quad (2)$$

where C_5 and C_8 are Capacitors that are connected, and C_{stray} the stray capacitance such as patterns and IC I/O capacitance. The value is about 5pF. Parallel resonant crystals are used in oscillator circuits that contain reactive components, like C_5, and C_8. A load capacitance (CL) must be specified for the crystal to operate at parallel resonant mode. The values of capacitors ($C_5 = C_8 = 15pF$) and frequency of the crystal oscillator (12MHz) have been chosen according to applications note obtained from the manufacturer [1].

2.3 Interfacing ICSP and I2C Communication Ports

Two serial communication ports are used for VSPK operation: ICSP and I2C.

The In-circuit Serial Programming (ICSP) link found in Fig. 2 enables the user to program or reflash the VSPK's firmware by connecting to the PIC programmer. ICSP gives access to programs without disconnecting the microcontroller from the circuitry. ICSP can be activated through a simple 5-pin connector and a standard PICmicro programmer supporting the Serial Programming model. The five ICSP pins include a program data (PGD) pin, a program clock (PGC) pin, a Vpp (MCLR) pin, a Vdd-5V (power) pin, and a Vss (ground) pin. The MCLR/VPP pin is normally connected to an RC circuit ($R_{27}C_4$). This circuit can affect the operation of ICSP depending on the size of the capacitor since the VPP voltage must be isolated from the rest of the circuit. A pull-up resistor (R_{26}) is tied to Vdd and the capacitor (C_4) is tied to the ground. The Microchip programming specification states that the device should be programmed at 5V. Special considerations have been made by using a regulator LM1117 to produce the necessary 3.3V to supply the programming of the microcontroller and other external circuits. The values of the resistor ($R_{28} = 100\Omega$), capacitor ($C_4 = 100nF$), and the pull-up resistor ($R_{26} = 4.7k\Omega$) have been chosen according to specifications from ICSP design guide [10].

Inter-Integrated Circuit (I2C) communication port is a synchronous, multi-master, multi-slave, packet-switched, single-ended, serial communication bus, widely used for attaching lower-speed peripheral ICs to processors and microcontrollers in short-distance, intra-board communication. It is a widely used protocol for short-distance communication, also known as the Two Wired Interface(TWI). The I2C uses the DS1307 serial real-time clock (RTC) which is a low-power, full binary-coded decimal (BCD) clock/calendar plus 56 bytes of NV SRAM. The internal oscillator circuitry of the RTC is designed for operation with a crystal having a specified load capacitance (CL) of

12.5pF. The suitable crystal oscillator (32.768kHz), and the values of pull-up resistors ($R_7 = R_8 = 4.7k\Omega$) have been selected according to these specifications obtained from the DS1307 datasheet [9]. According to these specifications, the maximum pin capacitance for SCL and SDA is $10pF$ and the maximum Rise Time (t_R) of Both SDA and SCL Signals is $1000ns$. Therefore, the maximum value of the time constant obtained with ($R_7 = R_8 = 4.7k\Omega$) is :

$$\tau_{SDA} = \tau_{SCL} = 470ns < 1000ns \quad (3)$$

This inequation shows that the components for the I2C bus are well selected for the good performance of VSPK.

2.4 Interfacing Input & Output Peripherals

The VSPK is equipped with input and output peripherals, which are LEDs, push buttons and LCD. For the three LEDs, the corresponding resistors (R_5, R_6 *and* R_{19}) are calculated and selected according to the following condition:

$$R_i > \frac{V_{dd} - V_{LED}}{I_{IOmax}} \quad (4)$$

Therefore, $R_5 = R_6 = 1k\Omega$ and $R_{19} = 100\Omega$ have been chosen to interfacing the LEDs. The smaller value of R_{19} permits obtaining a high blinking light during the programming. According to the electrical specifications, the values of resistors $R_1 = R_2 = R_{10} = 100\Omega$ are suitable to connect the push buttons. Four push buttons are used: BP1 is the reset button connected to the MCLR pin while the other three buttons (BP2, BP3, BP4) serve for user control purposes; and are mapped to RA3, RA4, and RA5, respectively.

The LCD is a (128x160 pixel) color display with an internal controller, ST7735R. Three serial peripheral interfaces (SPI) pins (SCK, MISO, MOSI) of 16LF18856 mapped to RC1, RC2, and RC0, respectively, are used for communication with the ST7735R. The VSPK possesses a series of three LEDs (D1, D8, D9) which serve as output displays and are connected to RB7, RC6, and RC7, accordingly.

3 Prototype Execution and Main Features of VSPK

In order to achieve the goal of producing the prototype in real-time and to prevent fatal events that may occur in the development process, the various parts of the kit were tested for performance evaluation before their integration to form the kit [16]. The bottom and the from views of the Kit are presented in Fig.3a and b respectively. On the bottom view the microprocessor in black color is well visible at the center, followed by the peripherals components including LEDs, functional circuits, pins,... while the bottom view presents the LCD and push buttons.

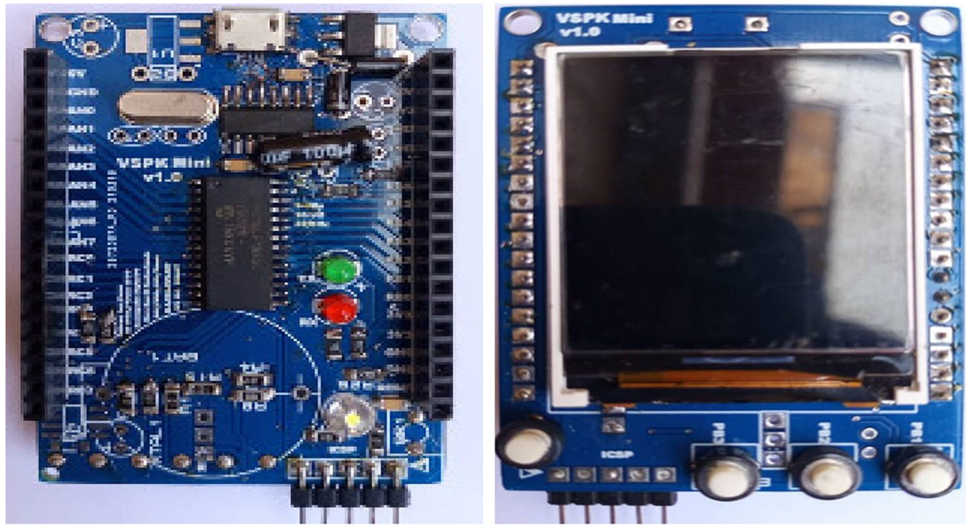
The main features of the proposed Kit are given below:

- eXtreme Low-Power (XLP) technology PIC16(L): the PIC16LF18856 with the necessary elements for its functioning already connected (oscillator, Reset circuit, power supply, etc.).
- C Compiler Optimized RISC Architecture with 16-Level Deep Hardware Stack.
- 24 I/O externally accessible and the connectivity to PC through USB port.
- a Real Time Clock/Calendar (RTC) with I2C protocol connected.
- Four push buttons and three LEDs already connected; a Graphic color LCD connected (128x160) pixel display which accepts texts, color pictures, shapes and is a drawing surface for any waveform.
- Power supply: The VSPK is powered by USB cable or 7V to 9V external DC source and is stable while functioning.
- The VSPK is compatible to C compilers(XC8-IDE MPLABX, MicroC Pro for PIC, CCS compiler), to MicroPascal for PIC (pascal language) and to MicroBasic for PIC(Basic language).
- The VSPK can be used for prototyping projects, designing and developing code-based control projects automation systems and basic control circuits.)

4 Comparative Study of VSPK and Arduino Uno Board

In this section, a comparative study between VSPK and Arduino Uno board is presented. The Arduino Uno is an open-source microcontroller board based on ATmega328 which includes 14 digital I/O pins, a power jack, 6 analog pins, a 16MHz crystal oscillator, a USB connection, a Reset button, and an ICSP header [4]. The software architecture is based on Arduino Integrated Development Environment (IDE) which includes a code-writing editor, a message area, and a toolbar with common function buttons [3]. The Arduino IDE is a cross-platform application written in Java [16]. Arduino Uno uses its own programming language (Embedded C or Arduino C), which is similar to C++. However, it's possible to use Arduino with other languages such as ArduBlock (visual programming with a snapped-together list of code blocks), and Snap4Arduino (based on the drag-and-drop visual programming language that permits a seamless interaction with almost all versions of the Arduino board). We conclude that Arduino Uno can be programmed using several programming environments (including the Atmel studio, now Microchip Studio for AVR devices) which are mostly for visual programming languages. Therefore, Embedded C remains the only language with written codes used by Arduino Uno.

On the other hand, the VSPK developed in this work presents some advantages, such as graphic color LCD, configurable internal oscillator, more than five PWM pins; flexible peripheral pin select; DAC that allows conversion of



(a) (b)

Fig. 3 **a** Bottom view of VSPK. **b** Front view of VSPK with LCD

numeric values to analog signals; configurable logic cell; signal measurement timer; numerically controlled oscillator; testing LEDs and testing buttons. The comparison between the VSPK kit and Arduino Uno board is shown in Table 1. The VSPK offers additional features to the ADC such as an 8-bit acquisition timer, Hardware capacitive voltage divider, automatic repeat, and sequencing; auto-conversion trigger, averaging and low pass filter, reference comparison, two levels threshold comparison, and selectable interrupts. The majority of the modules on the VSPK are remappable, giving the possibility to easily prototype, multiplex, and extend its capabilities. The VSPK is suitable for practical programming with or without the soldering of components. There is a means to display, use testing buttons, count time and calculate mean values for remote control applications. Furthermore, the VSPK can be widely used for attaching lower-speed peripheral ICs to processors & microcontrollers for intra-board communications and within short distances. Finally, VSPK is compatible with well-known C compilers (IDE MPLABX, MicroC Pro, CCS), to MicroPascal (pascal language), and to MicroBasic (Basic language) while Arduino Uno is more compatible with visual programming environments (ArduBlock, Snap4Arduino, Atmel studio).

5 Embedded Systems Courses Overview and Challenges

From an educational point of view, ES courses are developed on several platforms. For instance, the RESDEK aim is to train students who can design, build and program Arm-based ES using commercial application programming interfaces. The 7EDLK is a program for students to learn ES through distance education. The OPEES are available online to ease access to universal approaches in creative learning environments and information management. Some of these educational platforms (OPEES,7EDLK) operate only online while the others such as the RESDEK operate offline but remain unaffordable to students in developing countries. The higher cost of these applications including supporting, e-services, and network connectivity are requirements that are not easily met in developing countries [13]. Therefore, the VSPK becomes suitable for offline efficient teaching activities of ES to undergraduate students at low cost. A course based on the VSPK provides students with basic knowledge and skills that can be used in designing digital control units, industrial automation, telecommunication systems, etc. The summary of some course contents that can be carried out using the VSPK is shown in Table 2 where some theoretical and practical works are listed. The C language is used for programming in many ES platforms, because of some characteristics: code efficiency, readability, development time, and access to low-level control. Thus, it is essential for students to have some knowledge of C language, Assembly language, or other languages according to learning objectives, in order to implement their assignments and group projects. Learners can later develop individual projects starting from those proposed by their lecturers [19].

There are three essential steps that are necessary for progressive ES learning skills [8]. In the first step, students experience knowledge of hardware design using ES concepts, design components, and design procedures. The aim of the second step is to prepare students for the effective use of existing tools or kits such as the VSPK or other kits for ES design and programming development. Then, in the third step, students are involved in experimental learning, including simulation and practical. Since engineering practice is important in ES learning, high-level synthesis engineering experiential training is necessary for students who complete

Table 1 Comparison between VSPK and Arduino Uno board

Features	Arduino Uno	VSPK
Operating voltage	5V	3.3V
Recommended input voltage	7-9V	7-12V
Number of digital I/O pins	14	24
Number of analog I/O pins	6	24
Microcontroller	ATmega328	16LF18856
Configurable oscillator	no	yes
External interrupt on pins	2	24
DAC	0	yes (5bits DAC)
Flash Memory	32kB	28kB
SRAM	2kB	2kB
EEPROM	1kB	256bytes
Clock speed	16MHz	32MHz
CCP/PWM	6	7
Peripheral pin select	no	yes
Configurable Logic Cell (CLC)	no	yes(4)
CRC and memory Scan	no	yes
Signal Measurement Timer (SMT)	no	yes
Complementary Waveform Generator(CWG)	no	yes(3)
Digital Signal Modulator (DSM)	no	yes(3)
Timers	2-8bits, 1-16bits	3-8bits, 4-16bits
LCD module	no	128x160 pixels
USB port	yes	yes
SPI module	1	2
I2C module	1	2
Testing LEDs	3	3
RST button	yes	yes
Testing buttons	no	3
Real time debugging capability	no	yes (with MPLAB X IDE)
Visual Code Configuration	no	yes (with MPLAB code conf.)
Visual programming languages	several	no
Written programming languages	1	several (Basic, C, Pascal)
Physical structure of the board	very good	to be improved

designs with strict respect to hardware design and embedded system e-programming methods.

In the future, there are several outstanding challenges in ES education that must be addressed. The growing importance of artificial intelligence (AI) and machine learning in various ES applications must be included in emerging ES curricula (Data-driven and AI-based systems). Real engineering skills such as the ability to debug complex

Table 2 Contain of ES courses

Topics	Theoretical	Practical
Introduction to ES	Design & program an ES	
ES programming	Pointers	Accessing memory locations
	Serial communication	SW/HW implementation
	Image processing	SW/HW implementation
	Multiple interrupts	SW/HW implementation
	LCD interfacing and program	SW/HW implementation
	A/D conversion	SW/HW implementation
	D/A conversion	SW/HW implementation
	generate a sine wave	SW/HW implementation
Fundamental of control	Interfaces and protocols	HW/SW control
Executive automation	Control systems	SW/HW implementation

hardware and software components in industrial sub-systems is another future challenge. Systems engineering integration is the challenge of managing the development of complex technical systems in aerospace, defense, transportation, and energy grid industries. Ethical engineering is an important emerging challenge [6]. Many examples of negative social impacts of technology, such as facial recognition software that discriminates against people of color exist. As Embedded Systems become an integral part of human daily life, playing a significant role in social relations, there is a need to train future ES designers on the societal implications of technology, and to promote ethical thinking as they develop algorithms [6].

6 Experimental Setup with VSPK

The functioning of the proposed kit has been tested using multiple tutorial experiments on basic practical works possible with VSPK. Explanations on how to program the VSPK and use it to debug program code are given in the tutorial. Some essential works are equally presented in Table 3. Two illustrations from this pedagogical document are presented in this section.

6.1 First Test: Interrupt Service Routine System with Blinking LEDs

For the first test of the VSPK, we have considered a case study of the blinking LED controlled by a timer interrupt and push buttons with data transmission to a PC. The connection of VSPK to the PC needs a terminal program to be installed (Terminal20141030) and a USB-UART driver (CH341SER). The test program code performs many tasks in parallel, using the advantage of interrupt routines. It blinks a LED at a modifiable frequency (1Hz) which doesn't affect the other routines. It checks the buttons and performs the user's predefined task just the moment the user presses a button. It permanently receives any data available on the serial port, regardless of the main process. It samples channel 0 of ADC every 500ms, converts the content into a string, displays the result on the LCD, and subsequently sends the result to the PC through a USB-UART connection. The flowcharts of the main program and interrupt service routine of this case study are depicted in Fig. 4a, b respectively.

6.1.1 Results of the First Test

This first experimental test has demonstrated some operations performed by the VSPK: LED blinking, interrupt-based LED or push button ON/OFF, count & Display, and data transfer over a serial bus (USB) to a PC for storage and further analysis. Figure 5 presents the data collected and displayed through the USB-UART connection to a PC while Fig. 6 shows the same data displayed on the LCD simultaneously. In these figures, N represents the numeric value from the Analog to Digital Converter (ADC) after reading from pin RA0(AN0), and A represents the value of the voltage at pin $RA0(AN0)$ after the conversion of the numeric value N in Volt. It can be noticed that the value of A displayed on the PC terminal remains constant with time and this can be seen as a demonstration that the VSPK operates with stable parameters. The detailed program code of this first test is shown in Appendix A.

6.2 Second Test: Automatic Change-over System

For the second test, we have considered the application of VSPK for an automatic change-over system. In most of developing countries, the electricity supply for industrial, commercial, and domestic use is highly unstable. This gives

Table 3 Some basic practical works with VSPK

Title	Aim	External material needed
Led blinking	Blinking Led in main loop	None
Led ON/OFF	Blinking Led using timer interrupt	None
Led ON/OFF	Blinking Led using timer interrupt	None
Interrupt based Led ON/OFF	Use a button to turn OFF/ON	None
Blocking delay	Realize a delay in the main loop	None
IR remote control	Control lamps using an IR remote	IR remote
IR remote control	Control lamps using an IR remote	IR remote
Count,format & Display	count, extract digits & display	None
UART report/control	Send data, control loads	USB connect.& UART Term.
Digital Clock	Set time using RTC	None
Digital Voltmeter	Use ADC to set voltage	Potentiometer
Digital thermometer	Use ADC to set temperature	LM35 or ds18b20
Change-over system	Selection of a suitable source	Interface, voltage sensors

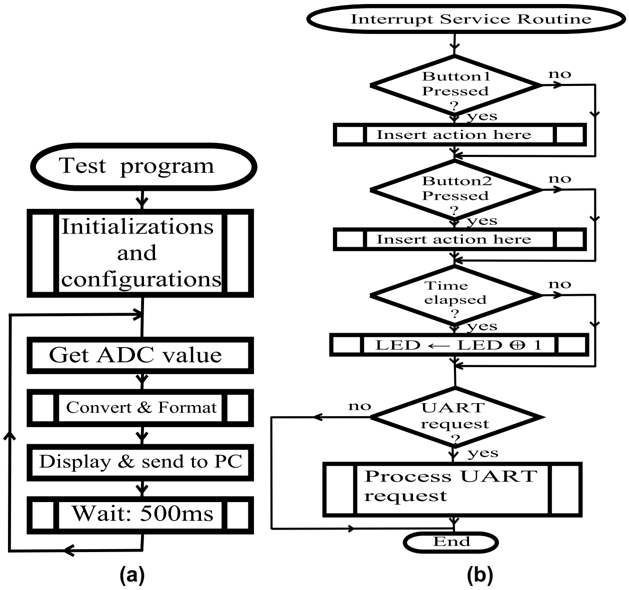


Fig. 4 **a** Main flow chart. **b** Interrupt service routine flow chart

rise to the frequent use of alternative sources of power supply to meet up with energy demands. The introduction of these alternative sources of supply brings forth the challenge of switching smoothly and timely between the main supply and the alternative sources whenever there is a failure on the main source. There is also the need to reduce drudgery from switching between the three sources which are Grid utility, Solar PV, and Fuel generator on the human side. The Automatic Voltage Change-over automatically switches over from the Grid utility to the other sources of power supply (solar supply and fuel generator) and provides a timer to switch between the sources. In case of low voltage, the switching follows the sequence from Grid to Solar, and from solar to Generator. It equally switches over back to the grid when power is restored and turns off the solar and generator sources automatically. The automatic voltage change-over links the load, the main supply, and the alternative supplies together. The functioning of the change over system is summarized in the flowchart diagram presented in Fig. 7.

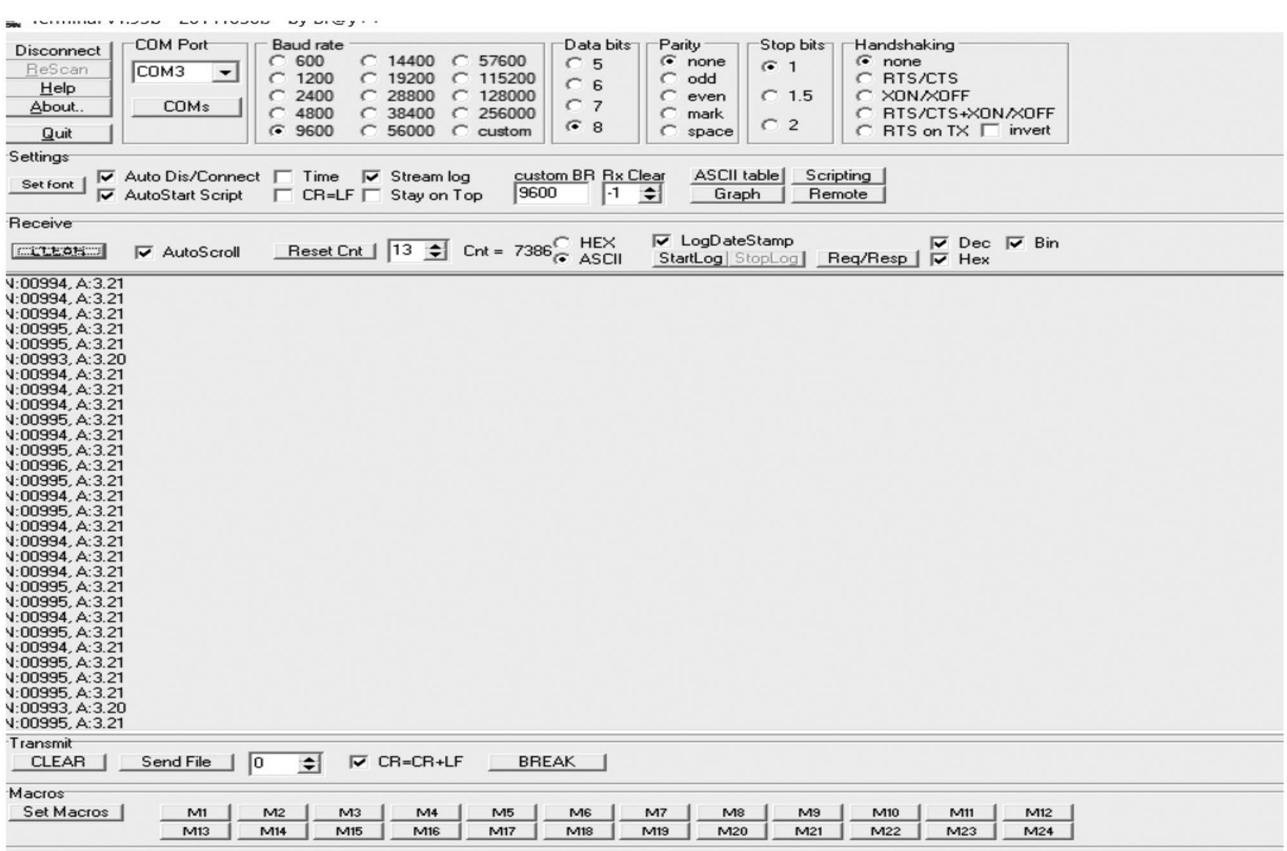


Fig. 5 Terminal on PC

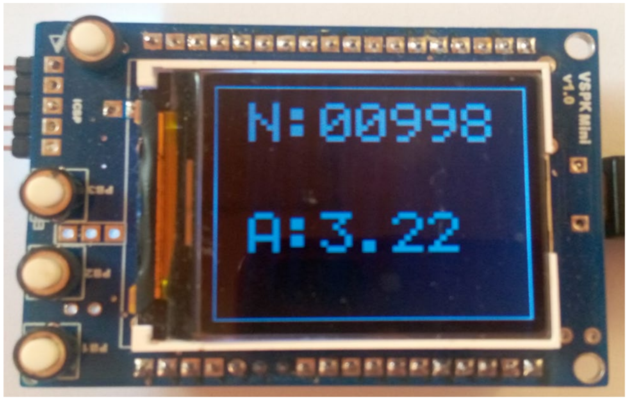


Fig. 6 LCD output

6.2.1 Results of the Second Test: Automatic Change-over System

When the system is put on, it checks the status of the three sources and displays them on the screen, then it switches on the source according to the priorities. If the grid utility (*ENEO*) set point is met, that is above 190*V*, *ENEO* comes on, irrespective of the other sources. The next priority is given to the Solar source, followed by the fuel generator. Our final circuit is able to switch automatically to alternative power sources when there is a power failure in the main supply. The most important part of this application was to design the interface and the voltage sensors module. This bloc is used to sensor the three-voltage coming from the various sources and give the value of each voltage at the output to the VSPK for him to compare them, and decide which of them will be considered as a priority. The LCD output of the change over in Fig. 8 presents the results displayed in the case of generator selected as the active source. In this case, the state of the generator is high, while the two other alternative sources are low.

7 Economic Evaluation of the Cost

An economic evaluation of the VSPK's cost has been performed based on the following elements: local cost of components, welding cost, PCB cost from Wonderfull PCB (HK) Ltd (China), debugging and testing cost, Added

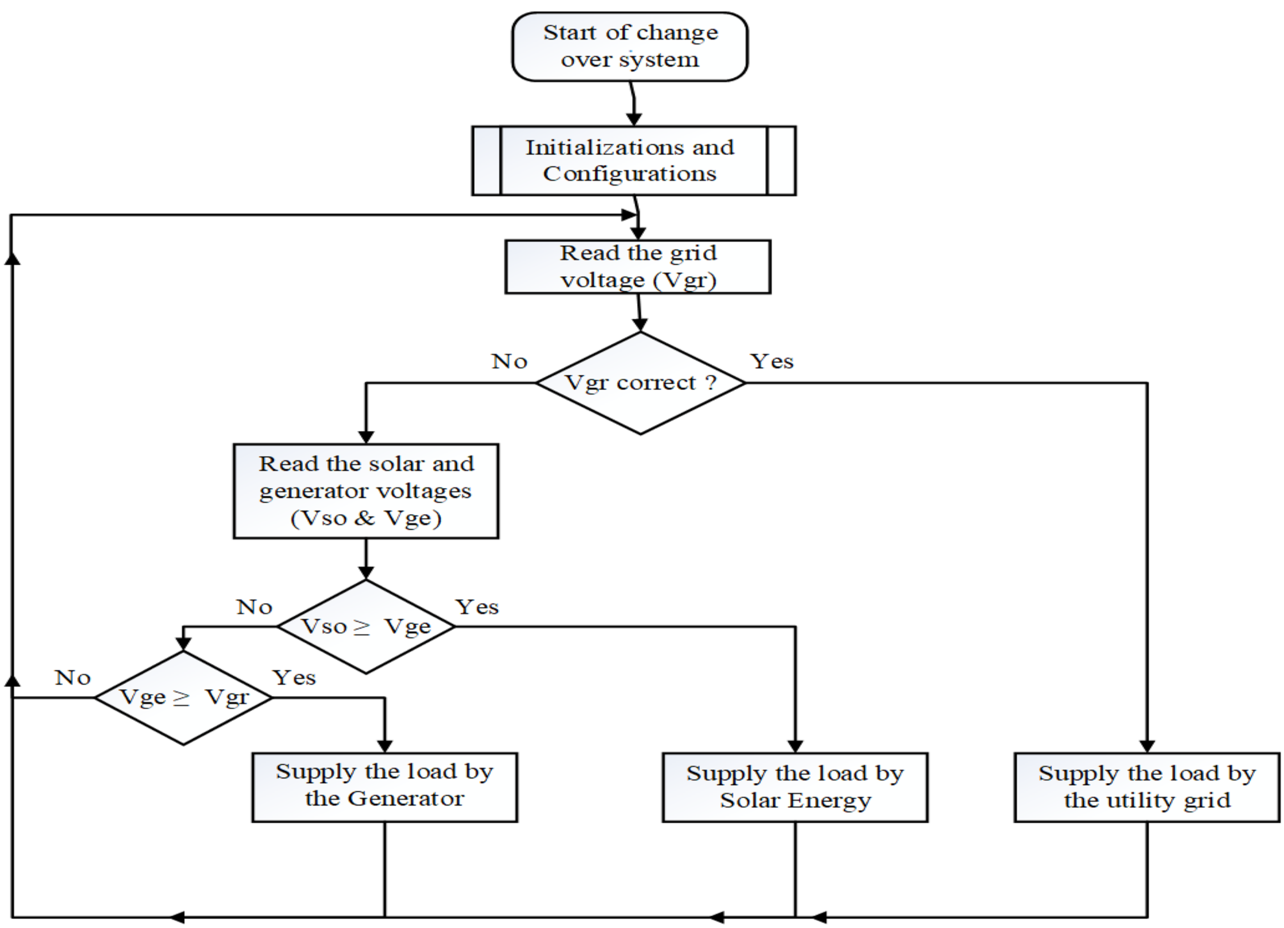


Fig. 7 Flowchart of change-over system

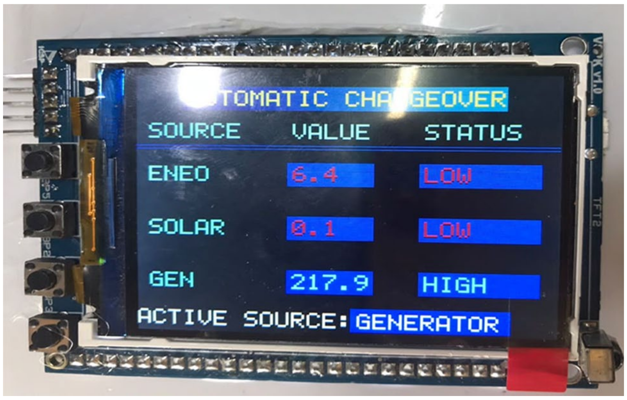


Fig. 8 LCD output of change-over system

Table 4 Price evaluation of the kit

Description	Cost for 30 boards
Local components	$180
PCB cost from Wonderfull PCB (HK) Ltd (China)	$150
Welding	$80
Debugging and testing	$100
Added value	$200
TAV 20%	$40
Total	$750
Cost for a single VSPK module	$25
Estimated Cost for Arduino board ATMega328p	$27

Value, Tax on the added value. The method used to obtain the cost of a single VSPK board consists of evaluating the economic cost of the series of thirty VSPK boards, then deducing the one of a single module. This is therefore compared to the cost of an Arduino Uno board purchased online. The evaluation method is summarized in Table 4 where the cost for a single VSPK module is estimated at $25 which is lower than the cost for Arduino Uno board ATMega328p Estimated at $27. This cost was obtained online from a commercial website (www.alibaba.com).

8 Conclusion and Future Work

In this paper, an integrated low-cost (less than $25) kit suitable for Embedded Systems testing and education in developing countries such as Sub-Saharan Africa has been developed. Despite the similarities between the proposed testing kit and the existing ones, the VSPK possesses significant features such as an integrated graphic color LCD, a configurable internal oscillator, more than five PWM pins, numerically controlled oscillators, testing LEDs, testing buttons, and multiple programming languages (various C compilers, MicroPascal, MicroBasic,...). The majority of the modules on the VSPK are remappable, giving the possibility of an easy prototype, multiplex, testing, and extension of its capabilities. The VSPK is suitable for practical programming and testing with or without the soldering of components. There is a means to display, use test buttons and perform remote control operations with the kit. The VSPK can be readily used for attaching lower-speed peripheral ICs to processors & microcontrollers in short-distance and intra-board communications. some case studies for the experimental test of VSPK have been carried out to practically validate the VSPK operations. The results obtained show that VSPK operates satisfactorily and provides good performance. Nevertheless, the need for enhancements concerning performance experiments and metrics to evaluate power consumption is really necessary to be investigated in the future development of this work and also to improve the prototype with more functionalities.

Appendix A. C Language Code of Interrupt Service Routine System

```
#include "config.h"
#include <xc.h>
#include <string.h>
#include <stdint.h>
#include <stdio.h>
#include "timer_library.h"
#include "kusart_16f1885x.h"
#include "adc_18855x.h"
#include "ili9163.h"
#include "screen_design.h"
#define LED LATBbits.LATB7
#define BLINK_TIME_MULTIPLIER 50
uint8_t var1;
uint8_t flag; /* declare the flag */
uint16_t adc_Nvalue;
float adc_value;
char str1[20]=" ", str2[20]=" " ,str1_cpy[20]=" ",
str2_cpy[20]=" ";
void configure_io(void){
ANSELA = 0x00; /* 'All Pins are digital*/
ANSELB = 0x00; /* 'All Pins are digital*/
ANSELC = 0b00000000;/* 'All Pins are digital*/
LATA = 0x00;
LATB = 0x00;
LATC = 0x00;
TRISA = 0B00111000; /* RA<5:3> as input, others
as output.*/
TRISB = 0x00; /* RB<7:0> as output.*/
TRISC = 0b10000000; /* RC<7> as input. others as
outputs.*/
WPUA = 0B00111000; /* Weak pull-up resistor on
PORTA, A<5:3>.*/
CM1CON0= 0x00;
CM1CON1= 0x00;/*No comparator active. */
PMD4bits.UART1MD = 1; /* disable UART module.
*/
IOCAN = 0B00111000;/*RA<5:3> as input. Inter-
rupt on RA4 when Low(Pressed);*/
PIE0bits.IOCIE = 1; /* IOC interrupt enabled.*/
INTCON I=0xC0; /*Global interrupt enabled.*/
return;}

/* INTERRUPT SERVICE ROUTINE PRO-
GRAM */

void _interrupt() interrupt_service_routine(void)
{ if(PIR0bits.IOCIF){
//——IOC for RA2 pin—————
if(IOCAFbits.IOCAF2){ IOCAFbits.IOCAF2=0;}
//——IOC for RA3 pin—————
if(IOCAFbits.IOCAF3){ OCAFbits.IOCAF3=0;
flag=0x00; //enable LED blinking }
//——IOC for RA4 pin—————
if(IOCAFbits.IOCAF4){ IOCAFbits.IOCAF4=0;
flag=0x01; //disable LED blinking }
//——IOC for RA5 pin—————
if(IOCAFbits.IOCAF5){ IOCAFbits.IOCAF5=0;
flag=0x00; //enable led blinking}
PIR0bits.IOCIF=0; // Clear the flag.}
/**********************************/
if ( TMR1IF==1) { TMR1IF=0; TMR1H = 0x33;
TMR1L = 0xF0; /*10ms update at 16MHz 0x63c0*/
if(++var1>BLINK_TIME_MULTIPLIER)
{ var1 =0;
if(flag==0) LED=1;
else LED==0;} //toggle LED.}
/**********************************/
if((RCIE) && (RCIF)){ // UART interrupt
rx_isr();
if(!RX_LISTENING){send_feedback(uart.rx_count)};
RCIF=0;}/*Message received. Process it.*/
if((TXIE)&&(TXIF)){tx_isr(); TXIF=0;}}
/*  End of interrupt service routine */

/* THE MAIN PROCESS */

void main(){
/*  Configuration of the processor */
OSCFRQ =0b101; //oscillator frequency set at
16MHz
configure_io();
/* Open UART with 9600 bauds and listen for a fixed
number of bytes*/
kuart_init_pic16f();
set_baudrate(BRG_IDX_9600);
kuart_enter_listening();
uart.rx_max_read = 5; // read max. 5 bytes.
adc_init(); // Open ADC
initialize_timer1(); // open the timer1.
for(;;)adc_Nvalue = adc_get_sample(0x00);
adc_value = adc_Nvalue 3.3/1023;// convert into volt .
sprintf(str1,"N:%05u,   A:%2.2f   ",adc_Nvalue,
adc_value);
kuart_print(str1);// send to PC.
screen_set_textsize(3);
screen_set_foreground_color(WHITE);
sprintf(str1," N:%05u",adc_Nvalue);
screen_wipeString(0,10,str1_cpy);
screen_drawString(0,10,str1);
strcpy(str1_cpy, str1);// keep a copy.
screen_set_textsize(3);
screen_set_foreground_color(CYAN);
sprintf(str2," A:%2.2f ",adc_value);
kuart_print(str1);// send to PC.
screen_wipeString(0,70,str2_cpy);// wipe the text.
screen_drawString(0,70,str2);// draw the new text.
strcpy(str2_cpy, str2); //keep a copy.
screen_set_textsize(3);
screen_set_foreground_color(CYAN);
sprintf(str2," A:%2.2f ",adc_value);
kuart_print(str1);// send to PC.
screen_wipeString(0,70,str2_cpy);
screen_drawString(0,70,str2);
strcpy(str2_cpy, str2);
_delay_ms(500);
return;
}
```

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Declarations

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Jean de Dieu Nguimfack-Ndongmo was born in 1971, in Dschang, Cameroon. He is a specialist in Electronic circuits and power systems. He was graduated from Advanced Teacher's Training College for Technical Education with DIPETI (Bachelor in Electrical Engineering) in 1995, then with DIPETII in 2005 from the University of Douala. He received a Master's degree (2010) in Electrical Engineering, and a Ph.D (2016) in Electronics, Electrotechnics and Automation (EEA) from the University of Dschang. He taught Electronic courses in technical secondary schools (Cameroon) from 1996 to 2014, and lectures at private and public university institutions since 2008. Currently, he is a Senior Lecturer in the department of Electrical and Power Engineering at Higher Technical Teachers Training College (HTTTC) of The University of Bamenda in Cameroon. His research interests include embedded systems, nonlinear control and applications to power system stability, FACTS, Energy conversion, Renewable Energy, and design of pedagogic tools for electronic education in universities and secondary schools. He is author of several scientific papers in electronic circuits and renewable energy systems. He is a member of the African Network for Solar Energy (ANSOLE).

Kevin Kentsa Zana is a qualified electronics teacher. He received a Master's degree in Process Engineering in 2022 from the University of Douala, a Second Cycle Technical Teacher Diploma in 2015 from the University of Bamenda, and a Bachelor of Technology in 2012 from the University of Dschang. He lectures at the private University SEAS/IUC since 2019, where he trains learners in designing and realizing electronics devices for various applications. Over the years, He has been developing didactic materials to ease teaching and learning processes by practice despite the lack of local suitable material. Some of his results are the electronics didactic workbench and electronic kits for universities and secondary schools. He aims to automate everything, equip laboratories and individuals of low incomes with necessary electronics material to boost creativity. When not teaching, He invents devices to solve real life situations and facilitate experimental research, enjoys embedded systems design and programming, general physical exercises, painting, cooking and reading.

Derek Ajesam Asoh is a Fulbright scholar with an inter-disciplinary doctorate in Information Science from the State University of New York at Albany, USA (US Department of State Fulbright Scholarship Award); and Master's degree in Electrical Engineering from St.

Petersburg Marine Transport Institute, Russia (Joint RussianCameroon Government Scholarship). His other academic qualifications through selfsponsorship include Certified Trainer and Facilitator, from Langevin Learning, Toronto, Canada and Master's degrees in Management (Engineering) and Administration (Health) from the University of Ottawa, Ottawa, Canada. Currently, he is Head of the Department of Electrical and Electronic Engineering (EEE) of the National Higher Polytechnic Institute (NAHPI), and Head of Division of Industrial Techniques (IT) of the Higher Technical Teachers Training College (HTTTC) both of the University of Bamenda, Cameroon. He lectures at NAHPI, HTTTC, and ENSPY (Ecole Nationale Superiéure Polytechique Yaoundé), Université de Yaoundé I, Cameroun. His current research interests include Renewable Energy and Energy Management Systems, Engineering Applications of Soft Computing and Artificial Intelligence Techniques, Electronic System Design and Automation, Educational Technology Tools, Engineering Education and Ethics, and Systems Design, Modeling, and Simulation. He is a member of the National Order of Electrical Engineers, Cameroon.

Nicole Adélaïde Kengnou Telem was born in 1977 in Dschang - Cameroon. In 2003, she was graduated from Advanced Teacher's Training College for Technical Education (ENSET), University of Douala, with DIPET 1 (Bachelor in Electrical and Electronics Engineering). In 2005, she obtained the DIPET 2 in the same institution. She obtained a Master degree in Electronics in 2012 from the Faculty of Science of the University of Dschang. She obtained the PhD degree in 2017 from the same university in Electronics. Her research interests are telemedicine, secure transmission of physiological signals and images, wireless communication and image processing. She is a member the African Network for Solar Energy (ANSOLE), and a member of both Laboratory of Electronics and Signal Processing (LETS) and Laboratory of Automation and Applied Computing (UR-AIA) of the University of Dschang.

René Kuate-Fochie is a specialist in power systems control and power electronics. He received a bachelor's degree in electrical engineering (2005), from FOTSO Victor University institute of Technology. Then, the M.Sc (2011) and the Ph.D (2020) in Electronics, Electrotechnics and Automation (EEA), from University of Dschang (Cameroon). Since 2021, he is an Assistant Lecturer in the Department of Electrical Engineering at FOTSO Victor University Institute of Technology. His research interests include FACTS Devices, power system stability and Control, Renewable Energy, nonlinear systems control using adaptive neural network. He is member of Laboratory of Automation and Applied Computing (URAIA) of the University of Dschang.

Godpromesse Kenné was born in Balatchi, Mbouda, Cameroon in 1967. He received the B.S. degree in electro-mechanical engineering in 1991, the M.S. degree in mechanical engineering in 1994, both from "Ecole Nationale Supéieure Polytechnique, Université de Yaoundé I" and the Ph.D. degree in Control Theory from University of Paris XI, France in 2003. He was a Guest Researcher at the "Laboratoire des Signaux et Systèmes (L2S), Centre National de la Recherche Scientifique-Ecole Supérieure d'Electricité (CNRS-SUPELEC), Université Paris XI", and the "Département Energie, SUPELEC", from September 2005 to January 2006 and from June to July 2006. Since 1996, he has been with the University of Dschang, Cameroon, where he is currently a Full Professor and Head of the Division of initial training at the FOTSO Victor University Institute of technology. He is founding member of Automation and Applied Computer Engineering Laboratory (UR-AIA). His research interests include identification and control of nonlinear systems using variable structure and neural network with applications in electro-mechanical systems.