Design and Development of Sensor-Based Mini Projects for Embedded System Laboratory Using ARM Cortex-M3(LPC1768)

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Abstract—**In majority of Indian Universities, advanced courses on embedded system design and its related laboratory are not available until the post-graduate level. Early exposure to embedded system design with advanced microcontroller is necessary for computer science and engineering students to face the design challenges in the today's world. This paper presents a mini project-based laboratory for learning embedded system design with different sensors. The aim of this laboratory is to motivate the students to learn the building blocks of embedded systems and control algorithm using the basic hardware and software programming skills provided in this paper, making use of ARM Cortex-M3 processor which is widely used in modern microcontroller products, System on Chip (SoC) and Application Specific Standard Products (ASSP). To enhance the learning process, students are allowed to take this laboratory in three sessions and sensor interfacing projects are provided in the third session. The sensor based projects developed with schematic circuits and software algorithm makes the students to perform all the projects easily and individually. The components including programmer/debugger are inexpensive and can be implemented as take-home projects. It also provides an opportunity to make use as hands-on experience which is then integrated by students to complete their mini project. The feedback from the students shows that most of them were motivated to learn actively all the skills included in the laboratory for embedded system design.**

Keywords-embedded system laboratory mini-projects; ARM Cortex-M3; LPC1768 Xplorer; hands-on experience; take-home experiments; sensors.

I. INTRODUCTION

Presently we are in the third generation of industrial revolution. Fruits of this generation are very significant and evident. The impact and presence of embedded systems is felt directly in our daily walk of life. Starting from cellular phones, digital cameras, biomedical and home appliances up to ubiquitous and sensor networking, embedded systems are used [1]. These systems are used to measure different parameters like temperature, humidity, position or velocity of mechanical systems etc.

In the present scenario of teaching embedded systems, topics like: Application Specific Integrated Circuits (ASIC), System-on-Chip (SoC) have gained prominence besides the computer architecture, organization and design in the field of electronics, electrical and computer engineering, and information technology (IT). In majority of Indian universities, computer engineering curricula have shifted their focus from computer architecture and CPU design to systems built around with highly integrated microcontrollers and embedded systems. Such a fact was also described by Yao Li [2]. The opportunities of embedded system design are growing exponentially but it requires creative ideas and noval technologies. Hence it is essential for students and engineers to learn how to design embedded systems. Further, while learning the design methodology of embedded systems it is interesting and difficult because it includes many areas such as: microcontroller architecture and programming [3, 4], interfacing technology and sensor technology [5] etc. Designing an embedded system laboratory is an art [6, 7], and it demands talented students to take up the design challenges keeping the time frame in their mind. Some difficulties in setting up of an embedded course and the related labs were described by Li Tu and Jun Yang [8]. It was also pointed out in this paper that embedded teaching has its own characteristics and teaching rules, and it requires a special method. Inspite of the best drafting at theoretical level, it is unsatisfactory training at laboratory level, which lacks exposure to advanced training and hands-on experience to the student at all levels.

To speed up learning and executing processes, and motivate students to involve actively, low-cost, take-home mini-project – based learning approach with different sensor modules is described in this paper. Although many papers [9-11] described and proposed an embedded system design curricula with hardware and software, these courses are quite expensive.

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For more than a decade, microprocessors and microcontrollers were taught at graduate and post-graduate levels at our university. Students used trainer kits (8085, 8051, AVR, PIC) during laboratory training and for their final projects. With the development and recent trends in technology, and increasing needs in modern embedded applications such as digital signal processing (DSP), 8-bit microcontroller architectures are getting obsolete. Keeping these aspects in view point, we are proposing a set of project based experiments. All the projects involved in this laboratory make use of NXP's ARM Cortex M3: LPC1768 microcontroller. This platform has strong community support, an online compiler, high performance, very easy to interface on a bread board and can be programmed in standard C/C++.

We have designed and developed a set of sensor-based interfaces using LPC1768, which are conventional and project oriented. Thus, our intention is to convey the information that these project-based experiments is not costly, also fits well with rest of the curriculum, fulfills as many educational goals as possible. The low cost sensor based projects are proposed in this paper serves as a good activity on which students can learn embedded system design skills because it covers not only common embedded system peripherals but also sensor calibration algorithms and real time control firmware implementation. This approach differs from the previous embedded system design used to calibrate the learning activity [12]. The students are allowed to discuss the hardware and software problems with each other while performing each project, although certain identified group of 3 or 4 students together will execute the project. Further, the students are tested individually, about their contribution to the project and knowledge on embedded system design, by peer assessment.

The following sections are organized as: Section-II gives design of embedded system laboratory course and a brief description of the architecture of ARM Cortex M3: LPC1768. Section III gives the details of sensor interfacing projects with hardware and software, developed in the present study. Conclusions and scope for future work are included in Section IV.

II. EMBEDDED SYTEN LABORATORYAND ARCHITECTURE OF LPC1768 CONTROLLER

A. *Embedded System Laboratory (ESL):*

Laboratories and experimental implementations are essential for learning basic embedded system designs [13]. Minimum requirement to learn embedded system design are:

- Knowledge of Microprocessor architecture, Peripheral working and analog/digital design
- Programming skills in "C and C++"
- Understanding embedded systems, their importance and application areas.
- Working principle of different peripheral devices, sensors and its interfacing with the microcontroller

In view these points simple structure of our embedded system laboratory is designed as shown in Table I. Session III include sensors used in the present work besides LEDs, switches seven-segment displays, dc motor and steppper motor (Session-I).

TABLE I. Structure of Course:

Course	**Topics**	**Duration**
Session-I	Lectures on Basic architecture of LPC1768 and simple interfaces using GPIOs : LEDs,switches,seven-segment display, dc motor and stepper motor	**One week** Theory: 2 Hours/day Lab: 2 Hours/day
Session-II	Lectures on Peripherals and exploitation of on-chip peripherals :ADC, PWM, Timers, USART, SPI etc.	**One week** Theory: 2 Hours/day Lab: 3 Hours/day
Session-III	Project works using different sensor modules Temperature Sensor : LM35 Humidity Sensor :HSM20G Soil Moisture Sensor Gas Sensor : MQ5 Proximity Sensor	**Two weeks** Literature survey/group discussion/component selection/purchase For the final mini-project

B. *Architecture of LPC1768:*

The LPC1768 is a 32-bit mixed signal controller from NXP semiconductors, and is one of the most widely used architectures in a number of embedded systems such as mobiles, automobiles, industrial control etc. It consists of ARM Cortex M3 as its core with 512kB flash memory and 64kB data memory, which offers high level of integration and low power consumption. Salient features include:

- Operates in the range of frequencies12 to 100MHz
- It incorporates a three stage pipeline architecture of 0.91MIPS/MHz (fetching, decoding and running)
- Harvard architecture with separate instructions, local data buses and a third bus for Peripheral communication.
- Works at 3.3V power supply

The LPC1768 Xplorer is a small board (10cms X 2.5cms) which cost about 35$ [14], comprises of on-board Ethernet MAC, a USB interface that can be configured as either Host, Device, or OTG, 8-channel general purpose DMA controller, four numbers of UARTs, two CAN channels, two SSP controllers, SPI interface, three I2C interfaces, 2-input plus 2-output I2S interface, 8-channel 12-bit ADC, 10-bit DAC, motor control PWM, Quadrature Encoder interface, four general purpose timers, six output general purpose PWM, ultra-low power RTC with separate battery supply, and up to 70 general purpose I/O pins [15]. The USB interface provides the means for

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uploading the program and for communicate with the host computer.

The LPC1768 Xplorer board supports different operating systems such as: WINDOWS XP, CE, LINUX, Palm OS and so on. Fig. 1 shows the block diagram of ARM cortex. Keil μvision 4 IDE is used for the software development. Programming steps involved in the software development is described in Keil website [16].

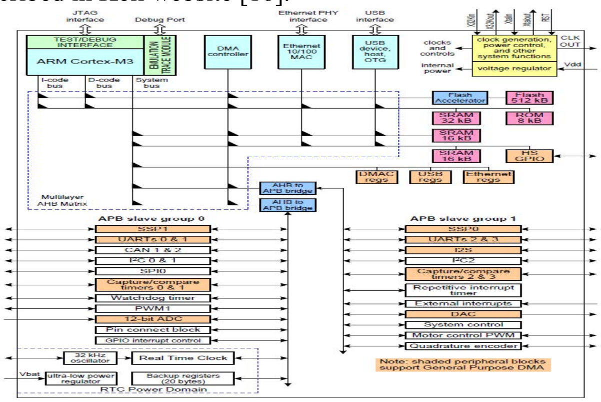


Fig. 1. *Block diagram of ARM CortexM3 (courtesy: NXP)*

Session 1:

This session covers the fundamentals of ARM microcontroller architecture and its features in theory. Based on the specifications provided by the kit, various experimental modules were developed with GPIO pins as an introductory course. In this lab session, students are asked to get acquainted with the Xplorer board by performing simple interfacing experiments using LEDs, Push Button, Seven Segment Display, LCD and Stepper Motor. Performing experiments of this session gives a better understanding in programming GPIO pins of LPC1768. Fig. 2 shows the photographs pertaining to this session.

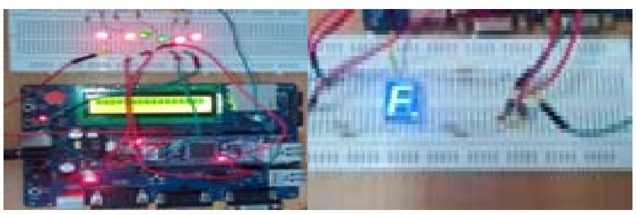


Fig. 2. *Photographs of simple GPIO interfacing experiments*

Session II:

In this session students were asked to interface the on-chip peripherals like ADC, PWM, Timer, and UART which are very essential to communicate with other devices like sensors, control devices etc., after the completion of the theory.

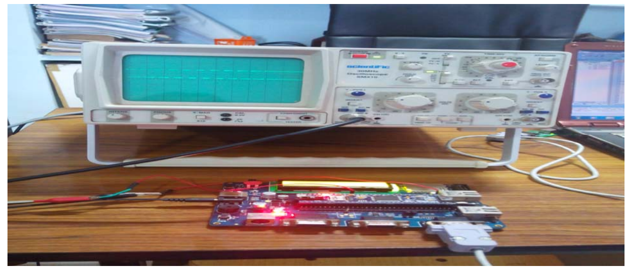


Fig. 3. *Photographs of wave form generation using PWM*

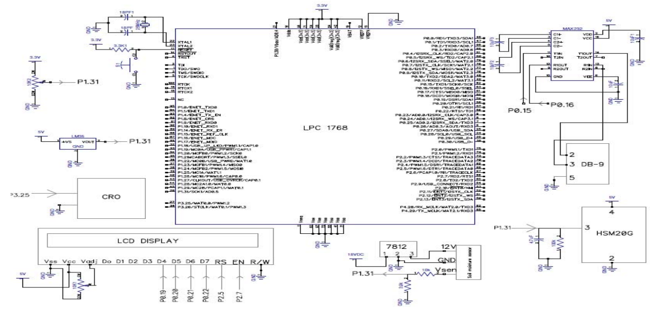
The goal of this session is to make the students familiar with the on-chip peripheral communication and the use of C commands. Students are asked to develop programs in embedded C. Fig. 3 shows the photograph of peripheral exploitation experiments.

Session III:

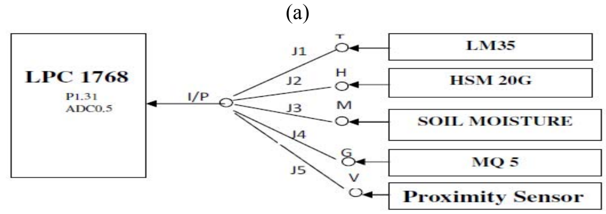
This session involves project-based laboratory training in which students are expected to design stand alone systems using sensors on their own. Hardware circuit along with simple software algorithms are developed by the students under the supervision of the internal guide. Sensor Interfacing Projects with Hardware And Software

The schematic diagram of the total projects described in this paper is shown in Fig. 4 (a). Majority of the projects use the on-chip ADC, UART and Timers. The important feature of the LPC1768 is that each pin is multiplexed (to reduce the pin-count), and it consists of 12-bit ADC. Key features of the on chip ADC are:

- Measurement range of 0 to V_{ref} (typically3V)
- 12 bit conversion time ≥ 5μs
- APB clock provides clocking for the ADC.



(a)



(b)

Fig.4. (a) *Circuit diagram of the sensor interfacing projects.*
(b).*Jumper settings for different sensor interfacing.*

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The microcontroller processes the selected sensor output to compute and display the parameter value on the LCD module. This is accomplished by connecting data output pin of LM35/ HSM20G/ soil moisture sensor/ Gas sensor output pins to the analog input channel (I/P) of the internal ADC0.5 (P0.31, via the jumper select (Fig. 4(b)). The reference voltage to the ADC is the same as the supply voltage to the microcontroller, i.e., 3.3V. The output voltage from the sensor is converted to a 12 -bit digital number and the internal software converts the digital value into its equivalent values and is displayed on the LCD module which is interfaced to LPC1768 in 4-bit mode. Following is the description of hardware and software corresponding to the individual projects.

Project1: Temperature measurement using LM35 temperature sensor with LPC1768-Xplorer :

One of the important features of the LM35 temperature sensor is that its output voltage is proportional to the temperature in degree Celsius [17]. Hence no extra calibration and compensation is needed. It draws a typical current of 60µA and hence self heating is negligible. Further this sensor is available in different packages, so that they can be used in different applications by preparing suitable probes [18]. LM35 gives an accuracy of ± 0.50°C over a temperature range of -55°C to +150°C. When used as a basic temperature sensor (2°C to 150°C) the output voltage Vout = 0 mV+10 mV/°C, that is, change in temperature by 1°C will result in a variation of 10.0 mV at its output. The pin layout of LM35 temperature sensor is shown in Fig. 5(a) and its typical application circuit is shown in Fig. 5(b).

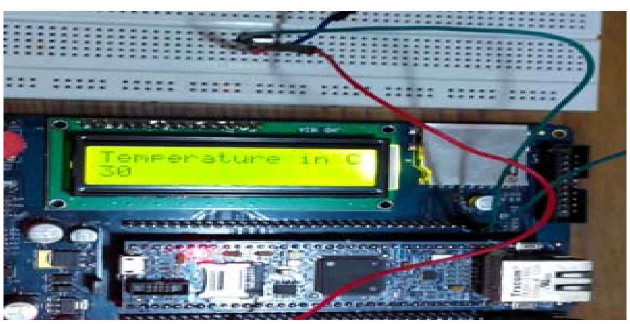

Fig.5. (a).*LM35 Temperature sensor, (b). application circuit (c). Temperature displayed on LCD module*

Analog input channel of on-chip ADC: AD0.5 (P1.31) is connected to the output pin: T of LM35 with the help of jumper J1. Fig. 6 shows the graph drawn between measured temperatures using LM35 temperature sensor in comparison with digital thermometer.

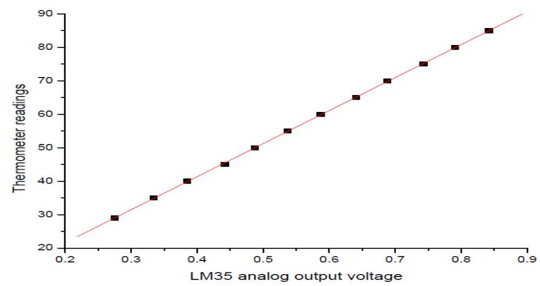

Fig.6. Graphical representation of LM35 analog output voltage verses thermometer readings

The software is developed based on the following flow chart fig 7, which is same for the projects 2, 3.

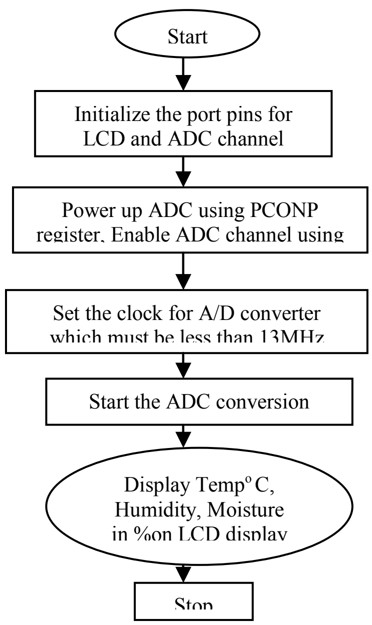

Fig. 7. Flow chart of the developed software

Project 2: *Humidity measurement using HSM20G sensor:*

HSM-20G humidity sensor is a device consisting of a special chip encapsulated in a plastic material whose electrical characteristics change according to the amount of humidity in the air. Basically it senses the amount of water vapor in air. Measurement accuracy (RH) is ±5%, and operating current of 2mA, input voltage range is 5.0V±0.2V and time response of 1 min .

Fig. 8 shows the application circuit and photograph of the humidity displayed on LCD display.

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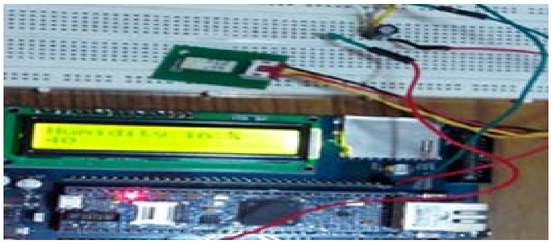

Fig. 8. *Application circuit of HSM-20G humidity sensor and photograph of thehumidity measurent*

Project 3: *Soil Moisture Sensor interfacing with LPC1768-Xplorer:*

Soil moisture sensor measures the water content in soil. This sensor consists of three probes in which only two probes are used to measure the water content of soil. The analog output of the sensor varies in the range: 0.6V to 12V. The output voltage is conditioned to suit the analog input voltage range of the on-chip ADC of LPC1768-Xplorer. Fig. 9 shows the application circuit of moisture sensor and photograph of the soil moisture displayed on LCD display.

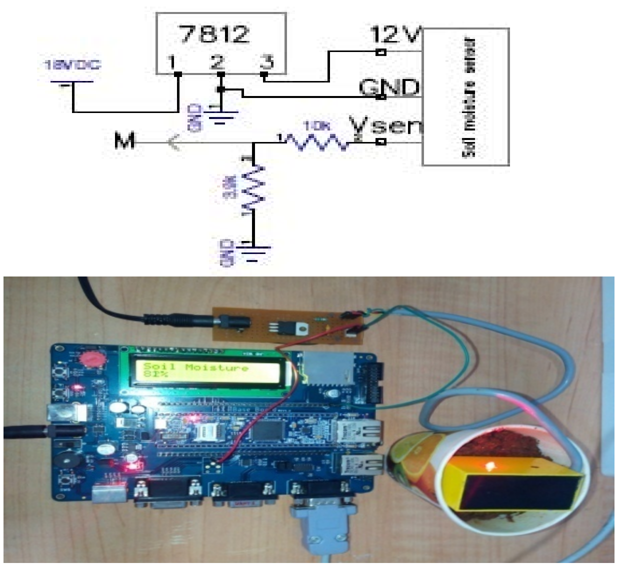

Fig.9. *Calibration circuit for soil moisture and Photograph of Soil Moisture displayed on LCD module*

Project 4: *RFID interfacing with LPC1768-Xplorer:*

RFID is a technology that uses radio frequency for communication between a tag (also known as transponder), and a reader (also known as interrogator). Further, the communication between the RFID hardware and the host computer can be established using two protocols:1. Serial protocol (RS232; 8-N-1) and 2. Wiegand protocol (26-bit format). In the present work, RS232 protocol using the on-chip UART of LPC1768 controller is carriedout. The software is developed based on the following algorithm.

1. Initialize the board.
2. Power up UART1 using PCONP register.
3. Configure peripheral clock for UART1 using PCLK SEL1 register.
4. Select P0.16 as RXD pins, Enable UART1 RXD and receive FIFO
5. Select 8 bit data length, no parity,1 stop bit using U0LCR register
6. Display the read data from RFID tag on the LCD display module.

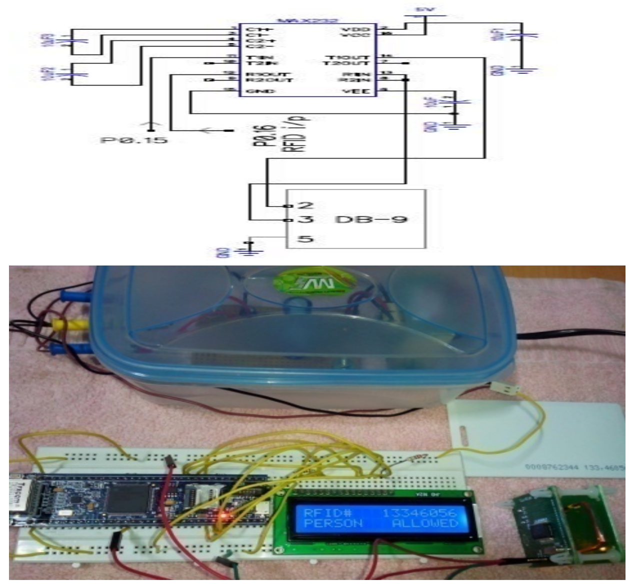

Fig. 10. *Photograph of RFID interfaced to LPC1768-Xplorer*

Project 5: *Angular/Linear velocity measurement:*

In the present method, we used a proximity sensor in measuring the velocity of rotating object. Spoiled CD is taken and a tiny piece of aluminum foil is cut and pasted near the rim of the CD. When this object comes in the proximity of sensor, the sensor gives a pulse. This output is converted to perfect square signal by a Schmitt IC (1/6 74LS14) and fed to the capture input of one of the on-chip timers of LPC1768. Fig. 11 shows the photograph of the angular measurement system. Software is developed based on the following algorithm.

1. Initialize the board.
2. Power up Timer using PCONP register.
3. Configure peripheral clock for Timer using PCLK SEL1 register and Initialize the LCD
4. Set pclk to 30 MHz
5. Enable P0.2 as capture channel0, load prescaler
6. Reset counter and prescaler, Capture on rising edge of channel 0

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Fig. 11. *Photograph of angular velocity measurement system*

A. Student feedback and Survey:

We got the feedback from the students by asking them to fill up a questionnaire. The result of the feedback is shown in Table 2 and fig 12.

TABLEII.The Average scores of the Survey for Project based laboratory

Questions	Score (0-5)
(a). What was your understanding about the lecture on ARM based system design?	4.5
(b). Are you satisfied with the ARM CortexM3 (LPC1768) lab kit?	4.8
(c). What was your understanding about hardware interfacing and software development?	4.7
(d). Are you satisfied with the hands-on experience and the type of mini projects?	4.5

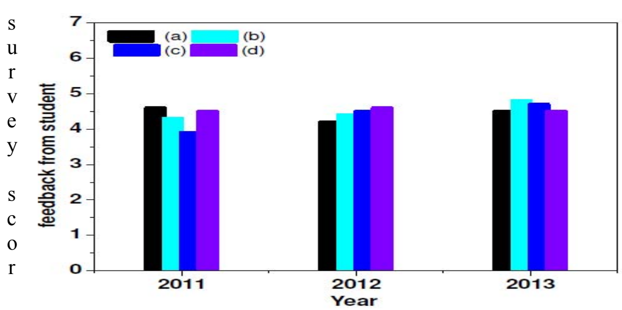

Fig. 12. Student's response to the questionnaire over a length of three years

III. CONCLUSION AND FUTURE WORK

This paper presents sensor projects useful for improving student's learning skill in embedded systems and preparing students to be useful in industry. Majority of the components used are inexpensive and hence can be take-home projects. Most of the students were motivated with the lab and the feedback from the students is positive. Further they also motivated on peer teaching for active engagement in classrooms. It is proposed to develop an integrated weather station by networking the sensors.

ACKNOWLEDGMENT

K. Aruna is thankful to the University Grants Commission (UGC), New Delhi, for sanctioning Junior Research Fellowship (UGC: No.F4-1/2006(BSR)/11-23/2008(BSR)).

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