CHAPTER 15

Extension Projects

Chapter Outline

15.1 Where do We Go from Here?

A vast number of peripheral devices and applications can be used with mbed projects. In the scope of this book alone it is not possible to explore every technology or peripheral device, but the design and programming techniques covered will allow you to investigate wider concepts to develop advanced projects using the mbed.

This chapter discusses a number of extension topics which suggest other areas for investigating and enjoying, as well as helping to bridge the gap between laboratory prototyping and the world of mass manufacturing. It is not possible to cover each of these aspects in detail, but an overview is provided to allow you to be creative in your approach to mbed projects and to give a springboard to more advanced and innovative systems.

15.2 Pololu Robot for mbed

Pololu manufactures a number of robotics and electronics kits for developing embedded systems. In particular, the Pololu m3pi robot, which features an mbed control board and a host of sensors and actuators, is shown in Figure 15.1. The robot has two wheels and is able to turn on its central point by rotating the wheels in opposite directions. For full details, see Reference 15.1.

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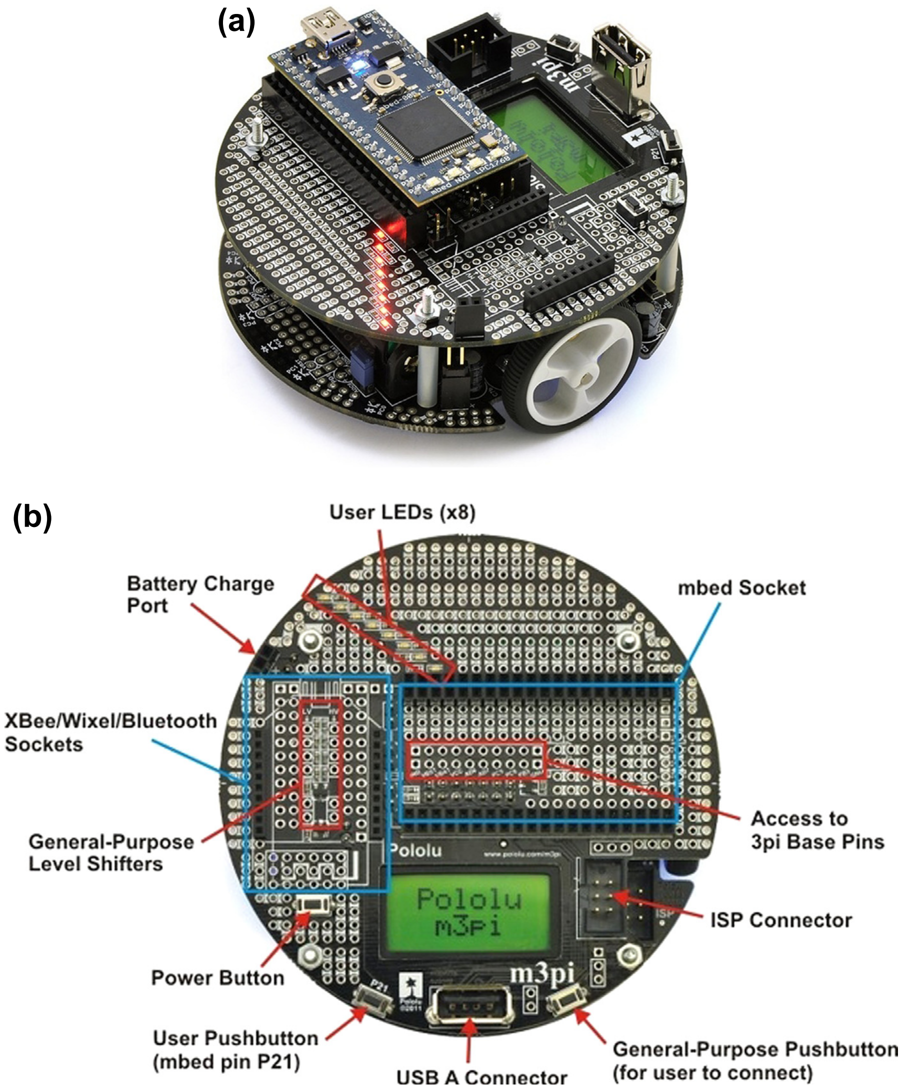

Figure 15.1:
(a) Pololu m3pi robot with (b) mbed control board (Reference 15.1). *(Image reproduced with permission of Pololu Corporation)*

The mp3i has an 8x2 character liquid crystal display (LCD) screen built in, as well as a number of buzzers and switches for input and output control. There are also several reflective sensors on the underside to allow development of line-tracking and maze-solving systems. Beyond this, there is a universal serial bus (USB) port and an XBee socket allowing wireless connectivity. Indeed, various projects have been prototyped by ARM to show the capabilities of the Pololu m3pi, in particular a system that allows control of the robot via a Nintendo Wii controller (see Reference 15.2).

15.3 Advanced Audio Projects

So far, the audio projects we have discussed have used very simple implementations of the analog-to-digital converter (ADC), the digital-to-analog converter (DAC) or the pulse width modulation ports. In addition, some very simple analog circuitry has been used when implementing simple digital audio sampling and analog reconstruction systems. However, the LPC1768 ADC is only 12-bit and the DAC is only 10-bit resolution, whereas high-quality audio generally requires 16-bit or even 24-bit resolution. Furthermore, having only a single DAC means that the mbed cannot directly output stereo (two-channel) audio. If high-quality stereo audio projects are to be developed it is possible to use a specialist ADC/DAC integrated circuit, such as the Texas Instruments TLV320AIC23b (Reference 15.3), which boasts stereo 24-bit resolution at sampling frequencies up to 96 kHz.

RS Components has announced the release of an mbed demo board (Reference 15.4) which includes a TLV320AIC23b ADC/DAC, and ARM has developed a number of libraries and support pages to interface the device (Reference 15.5). The mbed communicates with the TLV320 through an inter-integrated circuit sound (I^2S) port. This is a serial interface specifically designed for connecting digital audio devices together. We have not used it in this book, as it is not part of the 'official' mbed interconnection of Figure 2.1. However, it does appear in the LPC1768 block diagram of Figure 2.3, and there are means of routing it externally.

15.4 The Internet of Things

The Internet of Things is a phrase that has evolved to refer to a system of everyday objects and sensors being connected to the Internet, allowing remote access to information that can be used to control and enhance everyday activities, while interacting with the mobile Internet devices that people are now carrying (for example smartphones). Initially, the Internet of Things referred to global logistical systems that allow advanced stock control and real-time tracking of delivery items. For example, when an item is purchased from an online shop, the shop will have a detailed inventory of all the items held in stock. In general, when a shop receives items to its warehouse, the items are scanned in by an electronic system which evaluates some barcode data and automatically maintains an accurate stock register. When an item is dispatched to a customer, the item is scanned out of the warehouse and is subsequently scanned at various checkpoints along the delivery route, allowing the customer to log into an online portal and track the delivery of their purchase. On delivery, the customer will write an electronic signature into a portable device which will update the online delivery system to identify the item as delivered, and perhaps generate an invoice to be sent to the customer. The whole process happens automatically, allowing the item to have an online status and the customer access to the status information. The technology that allows this to happen is in the barcodes, the barcode scanners, handheld scanning and signature systems, as well as the Internet server hardware and software that manage the tracking information.

Technical advances in scanning and tracking processes are expected to continue, particularly with the development of cheaper and more advanced barcode scanners and the introduction of Quick Response (QR) codes which allow more data than a standard barcode to be encoded into an image. Figure 15.2 shows a QR code which, when scanned, will open the ARM mbed website. One advantage of using QR codes is that they effectively allow a one-way communication protocol with no wires and no electronic requirement in the slave system, which is very cost effective. They are also very tolerant to noise and image degradation. Using a QR code printed on an item, a QR scanner can find out a number of details about that item, essentially in a similar way to requesting a status message via any of the serial communication protocols previously discussed. People also have access to very accurate code scanners these days, as most smartphones are enabled with high-resolution cameras which, when equipped with barcode scanning software, such as that from RedLaser (Reference 15.6), allow many people to scan items with little additional hardware cost. The QR code cannot be changed, of course, so there are limitations, but dynamic QR codes may be an innovation for the future!

More recently, the Internet of Things concept has expanded to include everyday objects attached to the Internet; for example, allowing the data from a temperature sensor on one side of the world to be used in a bespoke mobile phone application being accessed on the other side of the world; or allowing people to control their household lighting and heating systems remotely over the Internet or via a smartphone, bringing potential fuel efficiency and home security improvements. In some cases the ideal application for this globally connected network of data and information has yet to be realized, but it is widely thought that this type of

Figure 15.2:
QR code linking to www.mbed.org

data access and control will become commonplace, especially if systems are made open access (i.e. at no cost) to software developers and network users.

ARM has recently developed a new concept for the mbed platform called 'WebSockets' (Reference 15.7). WebSockets allow mbed developers to prototype systems that adhere to the Internet of Things concept by giving webserver access to wireless- and Ethernet-equipped mbed systems. An mbed system can push sensor data to an ARM-managed WebSocket (a remote server) and the real-time data can be accessed globally by any Internet-equipped device. It is also possible to push data to the mbed through a WebSocket, hence allowing remote Internet control of the mbed system's features.

15.5 Introducing the mbed LPC11U24

In early 2012 ARM released a second mbed platform, the mbed LPC11U24, based on the ARM Cortex-M0 microprocessor architecture. This device is aimed predominantly at prototyping low-power, portable applications and specifically those requiring USB functionality. The NXP LPC11U24 microcontroller is a 48 MHz device with 8 kB of RAM and 32 kB of flash memory. It also supports USB, two serial peripheral interface (SPI) buses, inter-integrated circuit (I^2C) and universal asynchronous receiver/transmitter (UART) serial, and has six analog inputs and up to 30 digital input/output pins. The full pinout diagram for the mbed LPC11U24 is shown in Figure 15.3.

The mbed LPC11U24 is designed to have the same form factor and pin layout as the original mbed LPC1768, but with reduced functionality. So, in general, any programs compiled to run on the lower spec mbed LPC11U24 should execute with identical functionality on the mbed LPC1768. The mbed LPC11U24 is also specifically designed to have lower power consumption, so enabling prototyping of portable systems. Libraries for enabling sleep mode and interrupt-driven wake functions have also been implemented by ARM, and recent tests showed the device drawing 16 mA while awake and less than 2 mA while asleep. However, it must be remembered that the device itself is for prototyping and any resultant production design based on the LPC11U24 could readily do away with a number of mbed hardware features and potentially reduce power consumption to lower levels still.

A further application of the mbed LPC11U24 is as a key enabler for the Internet of Things and WebSockets concepts discussed earlier. The Internet of Things relies heavily on portable sensing devices and mass commercial take-up, so mobile communications, portability, low cost and low power prototyping are essential for these technologies to evolve. In addition to the mbed LPC11U24, ARM has developed a number of WebSockets libraries to allow mobile connectivity to the Internet, using the Roving Networks RN-131C WiFly module, which communicates with the mbed over standard UART serial (see Reference 15.8).

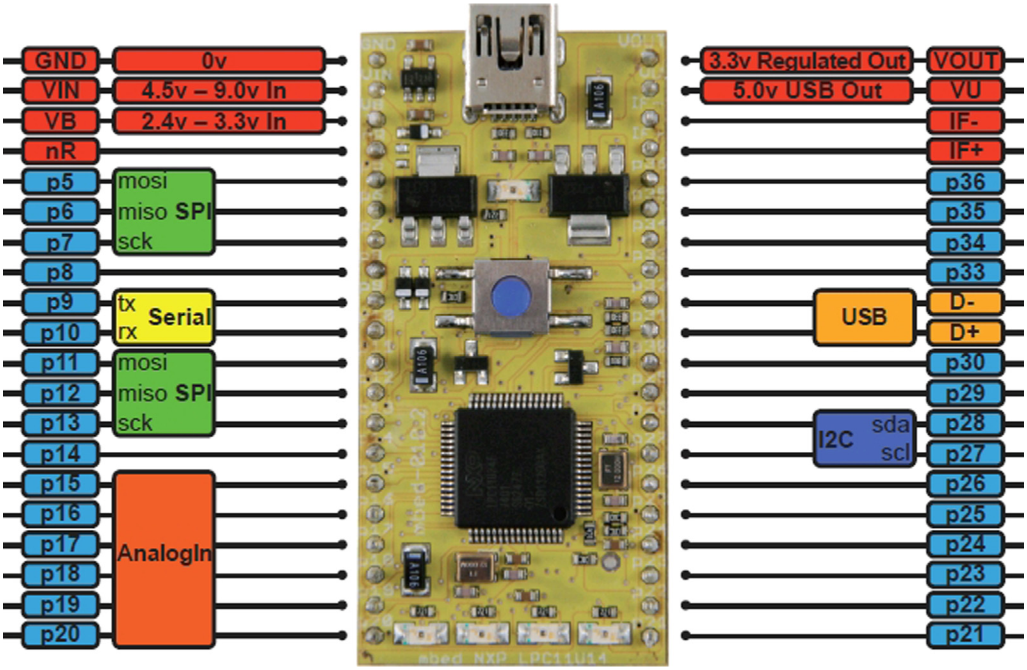

Figure 15.3:
mbed LPC11U24 pinout diagram. *(Image reproduced with permission of ARM Holdings)*

15.6 From mbed to Manufacture

The main thrust of this book has been focused towards rapid prototyping of embedded systems, using the ARM mbed. Rapid prototyping is an essential part of the design process, as it is the point where engineers need to see whether a design concept will work and how it should be implemented in hardware and software. The speed of this process is important, because companies need to know where to invest their research and development resources and which products to develop into mass-market systems. The mbed is an excellent device for accelerating this process as its ease of use and high-level libraries allow continuous testing during the prototyping and proof-of-concept cycle. The easier it is to test a system, the easier it is to develop accurate solutions in a short space of time.

There comes a time, however, when, if a prototype proves successful, a developer will wish to consider how the system could be engineered for mass manufacture and consumer use. At this stage a number of issues should be considered, in particular size, cost, power consumption, manufacturing methods, component availability and reliability, and quality control. So, the move from a working prototype to a commercially ready product is not an insignificant one, and the sooner these considerations can be incorporated into the design the lower the risk of drastic feature changes being required at a later stage. Figure 15.4 summarizes a product design cycle, from initial idea and concept development, through prototyping to final commercialization. The role of the mbed in proof of concept can be very clearly seen.

Although the mbed is designed as a rapid prototyping device, it is intended to allow a simple development path from prototyping to commercialization. In large companies, research and development engineers will prototype and evaluate design concepts and a different set of engineers may be required to take successful prototypes to commercialization. However, in small industries it is not uncommon for a single engineer to see a product through the entire development cycle, so engineers must also have a working knowledge of the manufacturing constraints when working on prototyping and product development.

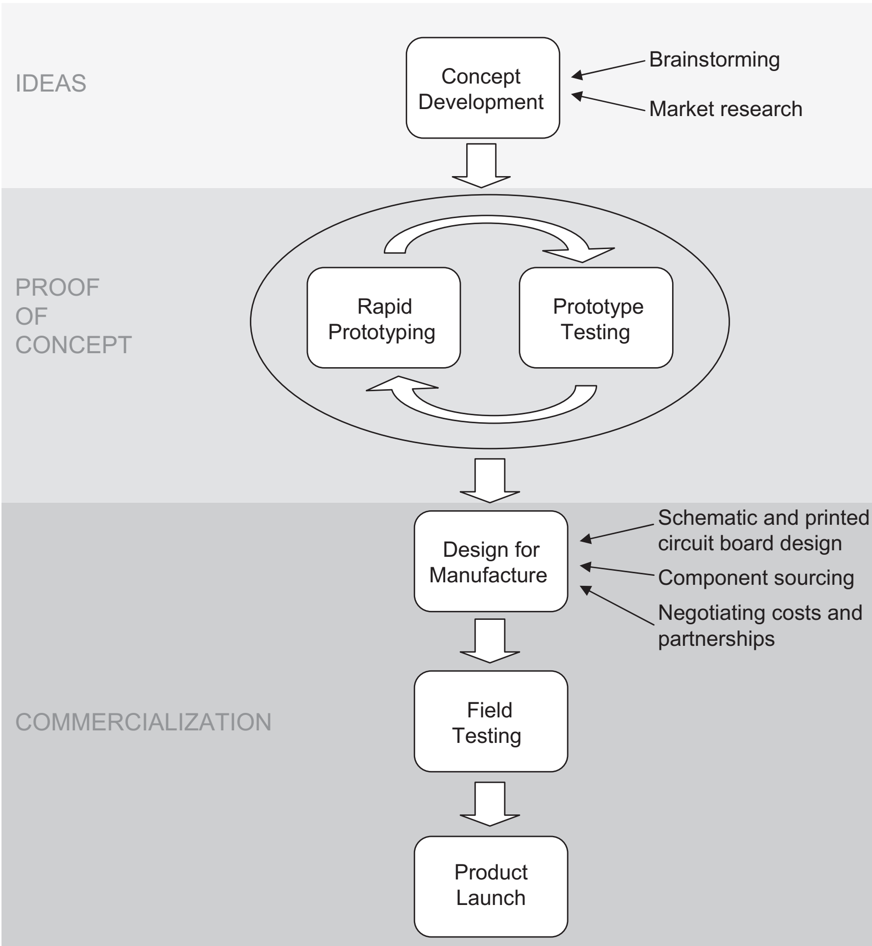

Figure 15.4:
A simplified product development cycle

If only a few commercial units are to be built, then it is quite feasible to use the mbed as it stands as the core controller of the system. However, where thousands of units are to be developed and sold, cost and size become very important factors. It is therefore desirable to implement the mbed hardware components on a custom printed circuit board (PCB) design, in order to minimize size and cost. Indeed, a number of hardware features on the mbed can be removed for certain hardware implementations, if developing a bespoke PCB, hence reducing cost and size further still.

Guidance on the process involved in taking an mbed prototype to the manufacture stage can be found in Reference 15.9, while Reference 15.10 gives a good example. Essentially, the USB bootloader hardware features on the mbed (those which allow drag-and-drop downloading of the .bin file) are only required for prototyping. Furthermore, if the application does not use Ethernet, then the Ethernet features can be left off the PCB design too. In a production system, the program binary file needs downloading to the LPC1768 only once, although this is an important part of the manufacturing process. It would be inefficient to populate the bespoke PCB with all the USB capabilities of the mbed simply to program the device once, but thankfully it is possible to use an actual mbed as a gateway device to the LPC1768 on the PCB, allowing the chip to easily be programmed.

Martin Smith's description in Reference 15.10 of the development of a bespoke PCB containing all mbed features, except for Ethernet, JTAG and USB, is a useful guide for anyone looking to develop their own mbed PCBs. The resulting PCB is shown in Figure 15.5. The process of programming the LPC1768 on this PCB through a second mbed is also described.

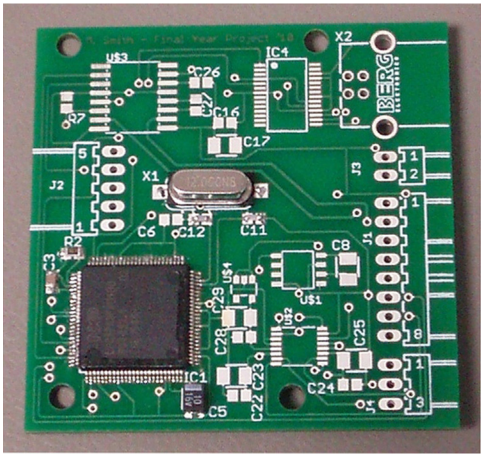

Figure 15.5:
Bespoke PCB based on the mbed, showing the LPC1768 in place. *(Image reproduced with permission of Martin Smith)*

15.7 Closing Thoughts

The mbed is shown to be a flexible and powerful device for the rapid prototyping of a number of electronic systems from electromechanical control to advanced Internet communications. The possibilities for projects involving the mbed are perhaps endless, and these latter chapters are intended to widen the developer's creative perspective and give some examples of how the technology described can be applied to bigger and more advanced projects.

The mbed itself is an innovative design, using a novel online compiler and a simple drag-and-drop USB interface. The aim is to make working with embedded systems simple, as often the learning curve is so steep that non-engineers rarely overcome the initial hurdles. The mbed is an excellent device to use for prototyping, education (both at early learning and higher education levels) and engagement between artistic and technological fields, where developers may not have a conventional engineering background. The idea is to make embedded systems design fun, accessible, yet productive, which the mbed does with ease.

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