Teaching Next Generation Computing Skills; The Challenge of Embedded Computing

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Abstract. As new paradigms, such as pervasive computing and ambient intelligence change the nature of the computer application market place, so do the skills and educational technology needed by students and teachers. The once dominant PC now finds itself outnumbered by several orders of magnitude by much smaller and cheaper embedded computers which can extend the internet from being just a means of connecting personal computers together, to enabling a world of connected "things"; the so-called "internet of things". In this world hundreds and even thousands of tiny service providing embedded-computers deliver a variety of services to us (some physical, some information) in ways that enable exciting new lifestyles and business opportunities. Applications range from the creation of digital homes (with their myriad of high-tech appliance), smart vehicles (cars aeroplanes & robotics) through to telecommunications (mobile phones, personal navigation or mobile learning). At the heart of this new technology is the "*embedded-computer*" which, from a software developers perspective, is significantly different to conventional desktop computers as they need to operate in real-time with computationally small resources and, in general, don't have inbuilt keyboards, displays or programming tools. All these factors conspire to bring significantly different educational and training requirements from older generations of computers, such as PCs. In this paper we examine these issues and introduce a set of modularised tools to arm universities, and other training institutions, with the means to support the acquisition of these key skills by students in a motivating and educationally sound way.

Keywords. Educational Technology, Embedded Computing, Computer Skills, Computer Training, , Microprocessor, AVR, ARM, mBed, Arduino, Lego.

1. Introduction

The computing world is undergoing huge changes as new paradigms such as "the internet of things", pervasive & ubiquitous computing, digital homes, intelligent cars, smart phones and robotics introduce a new era where embedded-computers dominate the application market [5] [6]. Embedded-computers differ from desktop computing in that the processors are integrated into products, such as TVs, washing machines cell-phones etc. Intel dominates the processor market for desktops but the embedded computing market is more fragmented with the company with the biggest market share being ARM that produces around 3 billion processors per year (90 per second)[2]. The embedded computing market is massive with some estimates suggesting it consumes

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[2] http://www.microbuilder.eu/components/ARM.aspx

in the order of 10 billion processors per year (some 98% of all processors produced), indicating embedded-computing is now the dominant (if somewhat unknown) computing technology. As Robert Metcalfe (Ethernet inventor and 3Com Corp founder) once famously put it *"just 2% of them (all the microprocessors produced) will go into PCs. Most will end up as part of that all pervasive fabric of computing that's being woven around and through our lives via a wide range of devices, some of which we don't even recognize as computers."* How, where and why has this "silent revolution" taken place? It's happened because it became cost-effective to use small and cheap processors (eg 4-32 bit) to control our everyday appliances, which now sell by the billion! To understand this phenomenon one just needs to consider how many computers are in our own lives; for example, telephones, faxes machine, answering machine, microwave oven, washing machine, dishwasher, refrigerators, coffee makers, televisions, digital radios, CD/DVD players, remote controls, etc contain at least one embedded computer. Also, an average car is said to contain around 20 microprocessors and even in what looks like a conventional PC, laptop or game console, numerous embedded-computers are integrated into peripherals such as the keyboard, disc drive; network-interface graphics cards etc. Thus, there may be 50 or more embedded-computers supporting our personal life which, when one considers the population of the world is approaching 7 billion people, adds up to a large potential market for embedded-computing. Clearly producing university graduates with the skills necessary for developing embedded-computer applications for this huge market-place is important but what are the issues and how do universities achieve that; this is the focus of the remainder of this paper?

2. Challenges of Learning Embedded Computing

Embedded computers are ones that are inseparably integrated into the physical structure of products and machines and usually have no screen, keyboard or software tools.

The mBed is based on the ARM Cortex-M3 Core running at 96MHz, with 512KB FLASH, 64KB RAM and various interfaces including Ethernet, USB Device, CAN, SPI, I2C

Figure 1. mBed - ARM-Cortex Based Embedded Computer Development Platform

Perhaps the most graphic way to understand the problems of developing embedded computing systems, is to look at a picture of one. Figure 1 shows a popular embedded computing device an mBed which contains an ARM-Cortex processor http://mbed.org/). If you come from a background of developing software for desktops, being confronted with such a "raw" computer would be somewhat of a shock! Questions that might arise are, where is the keyboard, where is the screen, what sort development software does it contain and how can you power it up? On top of this, embedded computers have comparatively low computational resources (low speed, small memory) and generally need to work in real-time (produce results in sufficient time to be useful). In a nutshell these are the problems of developing embedded system; they are entirely unlike conventional computers, so to make them do something useful requires special skills and tools [1] [3] [4]. From a computer science student's point of view, the main problems presented by embedded processors (of the mBed type) are:

1. Embedded-computers, as supplied from manufactures, are incomplete systems, and require extra hardware and software to make them do anything useful or interesting. Building such hardware and software takes more time than typical university laboratory sessions allow.
2. Computer science students have little or no electronic design expertise and, to undertake any meaningful functional design of bare embedded systems would require them to design and build various kinds of hardware input-output schemes and peripherals.
3. Once students have constructed hardware, the system has relatively fixed functionality that is difficult to alter, thus working against students getting experience of programming a wide variety of systems.

From an instructor's viewpoint the main problems faced by using regular embedded-computer tools for teaching are:

1. Doing things from the bottom up is time consuming and, within the limits of typical lab sessions, limits the complexity of the systems that students can build.
2. Much of the focus of the computer science curriculum is on the software aspects of embedded computing whereas existing embedded computing offerings revolve around the hardware level, which can distort the focus of the computer science curriculum.
3. System level solutions for embedded-computing education tend to either be single appliance oriented (eg a robot), or too simple to give realistic product development experience.
4. The software tools are sometimes overly complex, taking a lot of learning and distorting the focus of the underlying computing principles being taught.

In this paper we will present a modularised scheme of educational hardware and software technology that we argue will overcome these limitations.

3. A Modularised Approach to Engineering Design

Designing and developing embedded-computing systems is undoubtedly a complex process, in part caused by the raw nature of the technology (which involves low level hardware and software). In this work we have drawn inspiration from other complex systems and an often-used adage for managing them; "divide & conquer" which, in computer terms, can be interpreted as modularisation. Modularisation is widely used in computing and examples can be found in methodologies ranging from object-oriented programming to bus-based computer hardware. Modularisation is typically applied at multiple levels in the design and construction of computer systems. For example at a software level there are low level machine level microcode libraries and functions as well as high-level language libraries and functions. Likewise for hardware where, at the lowest levels there are ASIC chip libraries and at higher levels there are bus pluggable boards. A particularly interesting example for product level modularisation was described in an article in “Wired” which use the metaphor of atoms to describe methods for customised manufacture of products as large as cars and houses [2]. In our work we utilise such a modularised strategy by providing some 30 pluggable hardware boards (*Buzz Boards* – see Appendix A) that can be plugged together as described in the following sections to make a variety of embedded-computing applications. At the lowest hardware levels we have provided bread-boards that allow assembly of embedded systems at an electronic component level (suitable for those following electronic courses), and at a slightly higher level there is the option to attach mezzanine processor boards (such as the mBed board shown in Figure 1) whilst at the highest level it is possible to combine whole boards (see Figure 2). The system differs to more regular bus pluggable system in that instead of using a continuous shared bus, we have implemented a system of daisy-chained buses that provides the advantage of allowing systems to be constructed with physical forms that more closely mirror the final form of a product. For example, systems can be constructed that mirror the physical form of a mobile robot or an Internet Radio (albeit at a different scale). The use of Mezzanine processor boards allows the same underlying embedded computer infrastructure to be re-used with multiple processor types. Initially, we have started by supporting ARM processors, as these are the most widely used embedded processor, but we plan to launch a series of differing mezzanine processors such as AVR, Coldfire, 68K, and PIC. The flexibility afforded by this strategy will allow development of embedded-computing with different processors, for effectively the same expenditure, which is an important factor in providing broad based education and a bonus to industrial based developers who can move between processors as financial or performance advantages change. Thus, the scheme we are describing offers some strong benefits to educators, students and industrial developers alike. In the remainder of this paper we describe an innovative laboratory based development system for teaching embedded-computer design and development to computing and electronics students.

4. The Lab Development and Assignment Technology

In this section we will describe the modular component based embedded-computer development system we introduced in the preceding sections. The system is based on a series of hardware and software modules that are called *Buzz Boards*, which have been designed to make creating educational assignments and student projects simple and interesting. Our description is in two parts, *Buzz Board* hardware and software.

4.1 Buzz Board Hardware Platforms

To understand the embedded hardware concept, it is easiest to look at some pictures; figure 2 illustrates a few examples of these modules. Notice how most modules have through connectors at each end, enabling the units to be assembled in mechanical stacks, in various combinations, thereby allowing different functionalities and physical forms to be built. There are also other connectors to allow the units to be stacked in adjacent layers (see figure 4 that illustrates them being used to assemble a mobile robot). The full *Buzz Board* range is described in Appendix A.

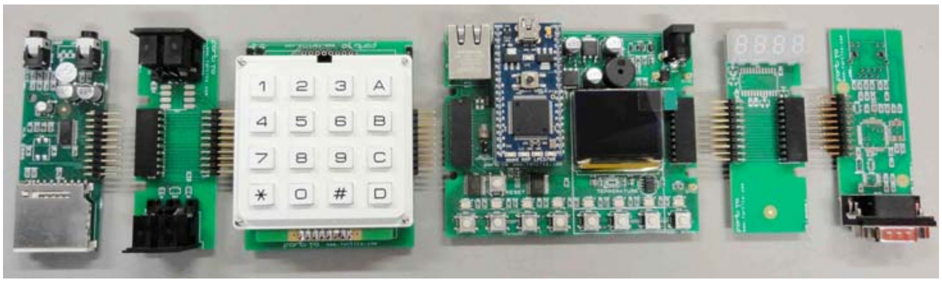

Figure 2. *Buzz Board* Examples - From Left to Right Audio, Midi, KeyPad, Base (Processor), LED & Network Boards

4.2 Buzz Board Software

Buzz Boards work with standard C and C++, the most common embedded-computing languages, *and* enable students and teachers to construct exciting and educational projects. In our system we use the widely used ARM microcontroller module that has a well-established developer following and online development tools [7]. In particular, our mBed option makes maximum use of the existing online mbed tools and software (see http://mbed.org/). The development software is based on a simple ‘drag & drop’ environment using web based development tools. The Processor Base Board is simply connected to a PC via a USB. Once connected it looks and behaves like a USB pen drive in which users drag and drop the compiled program onto the “pen drive” and then press the ‘reset’ button to execute it. A variety of software demos, and fully working assignment templates are provided (including software source code and the full text of assignments). There is also a web-based graphical programming environment under development for less experienced people. It uses a modular approach to hardware and software design in which programs are constructed by importing various programming blocks (*Buzz Blocks*) that are usually associated with the physical *Buzz Boards* used in the project. Internal code within the *Buzz Blocks* can be inspected and changed if required, but for programming at this level, such access is rarely required. The *Buzz Blocks* can be interconnected with the web-based IDE. *Buzz Block* have various inputs and outputs, each of which can be configured simply by clicking on it and the selecting from preset options. When finished a ‘make’ button is activated to compile and download a binary file to the *Buzz Board*, which can then be run by pressing the ‘reset’ button.

5. Assignments

By assembling the *Buzz Boards* is different ways (ie plugging them together in differing combinations) it is possible to create a variety of hardware application platforms that students can then program to learn differing skills and motivate them. In the following we describe some possibilities.

- **Games** - Using just the processor (mBed plus base board), the onboard OLED with buttons can be programmed to create games such as Pacman (maze based fun from the 70’s) or Reaction (pressing buttons in response to sounds or lights). By plugging-in peripherals more complex games can be created. For example, by adding the medical board a game called "Mind Battle" can be created by opponents using EMG signals from their brains to drive opposing graphical sprits.

- **Music** – Using the processor (mBed & base board) with one or more of the '16-button keypads' it is possible to write a program to create a simple musical instrument. By adding the A/D *Buzz Board* it's possible to create a guitar tuner and by adding the MIDI with the Audio *Buzz Board* a full synthetic musical system can be created. Later a dedicated guitar fret-board will be added to the range that only needs to be plugged into the processor board to work.
- **Media** – The *Buzz Board* set includes a number of camera options to allow a digital camera to be created (a miniature camera may be added directly to the processor base board or via the interconnect board). By adding the audio / SD storage module to the baseboard an MP3 player can be made.
- **Medical** – By using the 'medical' *and* 'battery' *Buzz Boards*, it is possible to create a variety of assignments such as a fitness or sports heart rate or body temperature monitor. By using the inertia sensor on the base board or adding the Navigation board then movement monitoring for outdoors sports can be implemented.
- **Network Services** – With the addition of the network *Buzz Board* its possible to implement an Internet radio
- **Computing Basics** - Using just the processor (mBed and base board) with the onboard OLED display and buttons (or the '16-button keypad' *Buzz Board*) a simple calculator can be programmed.
- **Weird-Science** – By plugging the Medical *Buzz Board* into the base board and using the physiological or EMG sensors, its possible to makes systems such as brain wave, lie detection and emotion sensing systems. Also, the use of a tunnel diode on this *Buzz Board* makes it possible to create a true random generator or, even to explore more exotic physics theories, such as making a 'quantum universe splitter'.
- **Robots** – The robot *Buzz Board* forms a chassis with wheels and infra-red (IR) distance sensors that can by combined with the processor base board to make a desktop mobile robot that can perform tasks such as line following, light seeking, maze escapes, crazy eyes (eyes following object proximity) and chatterbox (speaking what is 'sees').
- **Tools** – By adding the "Test Point" *Buzz Board* to the base board (with inbuilt tricolour LED's) its possible create instruments such as a multi-meter, oscilloscope, or logic analyser, or just use it to make connections to external test instruments easier.
- **Product Prototyping** – There are two prototyping boards (a bread-and a solder- *Buzz Board*) that allow electronic components to be assembled to make bespoke *Buzz Board* designs of the student's choice.

By way of two examples of such assignments, we will describe two of these in more detail, namely a *mobile desk based robot* and an *Internet radio*.

5.1 Internet Radio

Figure 3 shows how an Internet radio could be assembled by plugging together an ARM-Cortex mBed mezzanine, processor base board, network, keypad (optional) and audio *Buzz Boards*. The assembled radio has a wide range of features, including: keypad channel selection, button volume control, channel web information stored in FLASH memory, channel name and current music information displayed on the OLED screen, and stream recording onto SD/MMC memory card. When the 'Processor Base Board' is connected to a computer via a USB, it will appear as a pen drive. To program the Internet radio students may either write their own code or download pre-written software from the mbed site (http://mbed.org/), saving and compiling it on the computer before using 'drag and drop' to move the executable onto the mbed "pen drive". Finally, pressing the reset button on the 'Processor Base Board' will initialize and run the program.

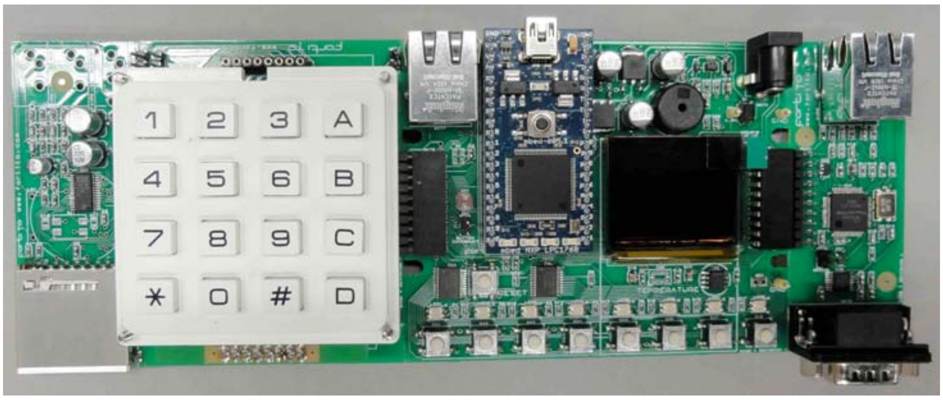

Figure 3. An Internet Radio constructed from *Buzz Boards* and comprising (from left to right) an audio, keypad, base & network *Buzz Boards*

5.2 Desk Top Robot Vehicle

Figure 4 shows how a desktop robot can be assembled by using a ARM-Cortex mBed mezzanine, processor base board, robot chassis (with IR proximity sensors and batteries), and two three-way inter board connector *Buzz Boards*. This is a simple task involving just plugging the boards physically together.

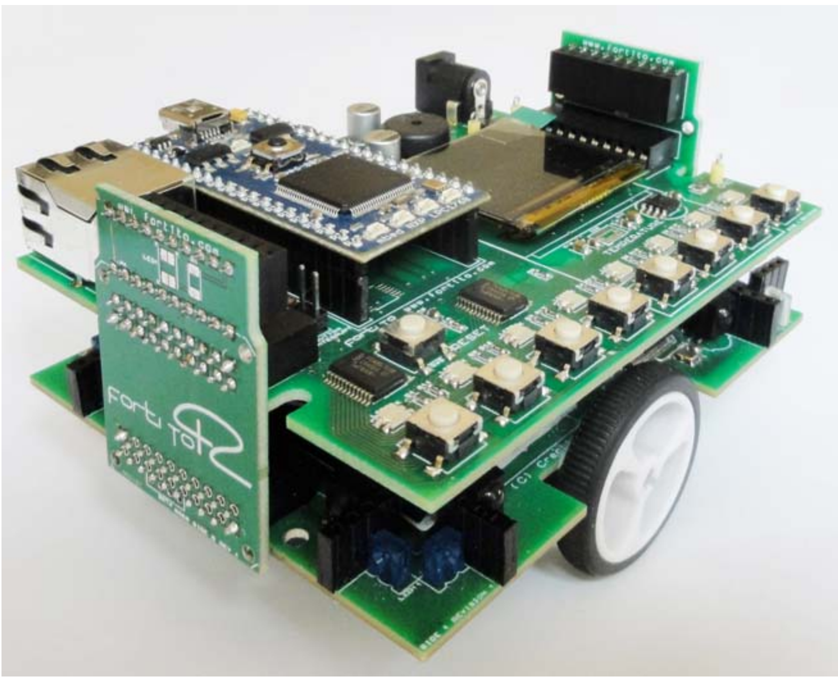

Figure 4. Desktop robot comprising Processor Base Board, Robot Chassis and two three way inter board connector *Buzz Boards*.

The finished robot has a wide range of features, including: 8 IR range finders, 5 Line following sensors, 2 Light sensors, Lithium-Ion Battery, 2 Dual mode gear-motors (with motor load monitoring & quadrature feedback), 8 Push buttons, 8 Tri-colour LED's, Ambient light level sensor, 3-axis accelerometer, Temperature sensor and a full colour high resolution OLED display. To program the robot the student either writes their own code or downloads the prebuilt software from the mBed site, saving and compiling it to their local computer. When the 'Processor Base Board' is connected the computers USB, it will appear as a pen-drive. Executable software may them be moved to the robot, using 'drag and drop'. Pressing the reset button on the 'processor base board' will initialize and run the program.

6. State-Of-The-Art - Contemporary Approaches

Besides the *Buzz-Board* educational kit described in this paper there are a number of other choices open to educationalist. By way of examples we will discuss three of the most relevant solutions, Lego, Arduino and mbed. The ARM based LEGO MindStorms kit is an educational toy that allows pre-university students to use a mix of Lego bricks (some plastic mechanical blocks, others electronic blocks) to build simple machines such as robots [8]. Whilst this is an interesting toy that supports creative design, the computer hardware is restricted to the use of proprietary (predesigned) modules based on I^2C interconnect. The use of the plastic brick construction makes electronic hardware development very difficult as, clearly, it was not a design goal of this kit. As a consequence there are many educational kits available that strive to enable students to experiment with electronics and computing at a more meaningful level. An example of such a system is the popular Arduino electronics prototyping kit which is widely used at school and university level. It is based on AVR processor [9] and provides a versatile approach to learning basic computer and electronics engineering. However, its age and open nature has lead to it being based on somewhat dated 5v devices (making it difficult to use with more modern 3.3v computer hardware) and its open nature has led to a somewhat diverse set of mechanically incompatible offerings, presenting some difficulties to users. However, the Arduino expansion system shows some promise allowing modules called 'Shields' to be attached but, it seems, only one 'Shield' at time can be connected, limiting the scope to develop interesting projects. A more modern, and increasingly popular solution to embedded computing design is provided by mbed, a partnership between ARM and Philips who have created a system to simplify embedded-computer design based on the Philips NXP LPC1768 Cortex-M3 MCU [10]. On the mbed website, the concept innovators, Simon Ford and Chris Styles, describe how they brought together a number of ideas to overcome problems they had found with students using earlier embedded-computer development systems, namely the idea for running the development tools online, the use of a mezzanine carrier for the processor (to make a working system) and making the processor memory appear as a USB disk, facilitating 'drag and drop' executables etc. This approach has found instant popularity with students and professionals alike, and the concept inspired us in our *Buzz-Board* design. In our approach, the idea has been extended to create a universal (processor independent) development system by providing an open system of pluggable modules (*Buzz Boards*) that accept mezzanine carriers with a variety of processors, thereby enabling support for both the mbed and Arduino systems (and more). In addition, the multiplicity of *Buzz Board* connection standards brings added versatility. For example, I^2C, provides a means of creating "super-bricks" for Lego.

6. A Competition – Embedded Computing Assignment Innovation

To promote the development of creative and more motivating embedded-computing assignments, at this workshop (IC'11) we are launching a '*Creative Assignment*' competition (supported by the *Buzz Board* manufacturers, FortiTo, a "Faculty Cooperative" venture) whereby the academic community (both teachers and students) are invited to submit ideas for assignments to be built from *Buzz Boards*. There are two categories of entry; ideas for assignments (based on existing or proposed *Buzz Boards*) or actual assignments (code and assignment documents) built from existing *Buzz Board*. More details are on the competition website[3].

7. Faculty Cooperatives

Our difficulties in finding appropriate commercial laboratory assignment solutions to meet our embedded-computing teaching requirements convinced us that practicing academics are the best people to design educational solutions for students. We also believe in the values of open-source shared tools and of enabling academics to have a stronger stake-holding in the companies that provide educational technology, in the belief that such companies would serve the interest of students and teachers better. Thus, FortiTo is formed as a '*Faculty Cooperative*', where a significant proportion of the shareholding is reserved for academics.

8. Summary

In this paper we have explained how emerging technologies such as pervasive / ubiquitous computing, and Ambient Intelligence, are creating new opportunities for companies whilst at the same time they are challenging educators as to how to teach the skills involved, which differ significantly from those associated with conventional desktop computing. These changes require different types of computational infrastructure and laboratory assignment support. In this paper we describe a solution based on a modular architectural approach known as *Buzz Boards*. There are a variety of *Buzz Boards* that allow experimentation with differing processor families and differing applications. The *Buzz Boards* support development of either hardware (via prototyping boards) or software (via using C/C++ or visual *Buzz Blocks*). Applications can be rapidly created by the teacher or students plugging together various combinations of *Buzz Boards* and *Buzz Blocks* to produce interesting functionalities. This technology will be demonstrated as part of the workshop presentation and discussion. Finally we have described how this venture has been created by academics, for academics, via the Faculty Cooperative scheme an approach we hope will prove beneficial to the academic community at large.

Acknowledgements
We are indebted to FortiTo Ltd (www.fortito.com) for the information on their product range and sponsoring the '*Creative Assignment*' competition.

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Appendix A - *Buzz Boards*

1. **Mezzanine ARM Processor** - 32-bit ARM-Cortex processor mbed board. The mbed Microcontroller is an NXP LPC1768 with an ARM-Cortex-M3 core running at 96MHz, 512KB FLASH, 64KB RAM and numerous interfaces including Ethernet, USB Device and Host, CAN, SPI, I2C and other I/O.
2. **Processor Base *Buzz Board*** – This carrier baseboard accepts a mezzanine based processor and comes with a set of on-board peripherals that allows numerous projects to be designed without the need for additional *Buzz Boards*. On-board devices include: 8 General purpose push buttons with interrupt output, 8 tri-colour LED's, temperature sensor, light sensor (with a spectral response that matches the human eye), audio sounder (that can also be used as a microphone), high-resolution full colour OLED display. It also includes on-board regulators that allow for both external 7-12V DC and USB operation plus a 12.2KHz-100MHz frequency synthesizer for external *Buzz Boards*. There are 2 bus ports that have I2C, SPI, and general purpose IO plus an optional 3-Axis accelerometer.
3. **Audio-SD *Buzz Board*** - This module is designed primarily as a high quality audio interface, but also provides a standard SD/MMC FLASH memory slot. Features include: 24-Bit codec, audio headphone output socket, microphone input socket, line in jack socket & onboard loudspeaker.
4. **Manual Control *Buzz Board*** - This module has controls of the type used in handheld games and includes: dual navigation switches with push button, dual rotary encoder switches. There is a through-bus allowing other *Buzz Boards* to be connected.
5. **Environmental Sensing *Buzz Board*** - A module to provide basic environmental information including: Air Humidity ±3%RH. Air Temperature ±0.4%°C. Air Barometric Pressure ±1%hPa and through-bus allowing other Buzz Boards to be connected.
6. **Navigation *Buzz Board*** - A GPS Navigation system with the following features: high sensitivity front-end, fast-acquisition hardware, a small onboard chip antenna & support for SBAS (WAAS, EGNOS, MSAS) protocols with a through-bus allowing other Buzz Boards to be connected.
7. **Inter-board Extension *Buzz Board*** – A 90mm bus extension designed primarily as a vertical tower to mount the 'IR Beacon' but it can also raise the working height of other sensors such as the ultrasonic *Buzz Board*.
8. **Inter-board Right Angled *Buzz Board*** - A small right angled bus adapter to allow greater flexibility when connecting *Buzz Boards* together.
9. **3 Way Inter-board *Buzz Board* -** A bus interconnector primarily designed to connect the 'Processor Base Board' to the 'Robot Chassis', but can be used in many other ways. This module also has the following features: a variable frequency (0.172-44Hz) high intensity LED that could be used for robot to robot interaction & an optional camera socket that facilitates the mounting of a full resolution colour camera with built in JPEG compression.
10. **Development *Buzz Board*** - This is a reusable high-quality development bread-board that is ideal in a teaching environment and can be used year after year (this is not a low quality breadboard

common to other systems). The main features are: the bus connector allows access to all lines including I2C and SPI interfaces with current protected 3.3V and 5V supplies. Premium quality prototyping breadboard. 470 * 2 General prototyping area. 80 * 2 Power rails (power and ground).

11. **Prototyping *Buzz Board*** - This is a PCB designed to solder in components to create prototypes. It has a matrix of plated through holes on a standard 0.1” grid. Adapters for metric SMD devices are easily sourced. Main features are: the bus connector allows access to all lines including I^2C and SPI interfaces. It features a high quality PCB (that allows circuit modification) with 720 plated-through holes and power/ ground rails with current protected 3.3V and 5V supplies.
12. **Keypad *Buzz Board*** - This is a high quality ‘16 button keypad’ that can be mounted either way up, allowing it to be used on either of the ‘Processor Base Board’ ports. It has the following features: optional interrupt output and a through bus allowing for other *Buzz Boards* or up to 4 keypads to be connected.
13. **LED Display *Buzz Board*** - This is a 4 digit 7-segment LED display with the following features: optional automatic or software driven display multiplexing plus a through bus allowing other Buzz Boards or LED display modules to be connected.
14. **Medical *Buzz Board*** – This features a high sensitivity low-noise amplifier suitable for EEG, ECG, and EMG signal acquisition. It includes 3 input channels, a common output plus an I^2C Socket that can interface to the ‘Biosensor Watch’ *Buzz Board*. Note: whilst the performance of this module has been shown to be equal or even better than some professional medical units, it is not calibrated or certified for such use.
15. **MIDI *Buzz Board*** - This offers an industry standard MIDI interface with the following features: MIDI in and out, opto-isolated input, standard 6 way DIN sockets and a through bus allowing other *Buzz Boards* to be connected.
16. **Multi Mode Motor *Buzz Board*** - A single DC gear-motor and interface featuring 3 basic modes of operation: 1) PWM speed control whilst in DC motor mode. 2) Stepper emulation mode allowing precise shaft positioning and rotation. 3) Servo emulation mode (1-2mS control) allowing servo control software development.
17. **Navigation *Buzz Board*** - This module offers two navigation related sensors. They are: 3-Axis Accelerometer ±1.5g with a sensitivity of 21.33 counts/g and a 2-axis compass with a 0.5 degree heading accuracy. It also includes a through-bus allowing other Buzz Boards to be connected.
18. **Network/232 *Buzz Board*** - This offers both an Ethernet and RS232 interface. The network interface utilizes the WIZnet W5100 IC, which includes a hardwired TCP/IP stack thus relieving the main processor to do other things. Supports TCP, UDP, IPv4, ICMP, ARP, IGMP, PPPoE, 4 concurrent sockets and full RS232 (with hardware handshaking).
19. **Quantum *Buzz Board*** - featuring a tunnel diode allowing generation of quantum events and random numbers. It provides: number generation up n-bits, push button and LED to support truly random 50-50 decisions. This module includes a through bus for connections to other *Buzz Boards*.
20. **RFID *Buzz Board*** - A radio frequency ID tag reader working in the common 125KHz band. This module uses the ID-12 receiver with internal antenna and has a through-bus to connect with other *Buzz Boards*.
21. **Robot *Buzz Board*** - A complete robot chassis that interfaces to the ‘Processor Base Board’. It include: 8 IR range finders (immune to ambient light levels), 5 line following sensors (immune to ambient light with auto adjust for low contrast lines), a balanced pair of light sensors to enable light following, a lithium-ion battery (with external DC charging jack or USB) providing 5 hours run time, 2 Dual mode gear-motors (PWM or stepper emulation; withotor load monitoring and quadrature motor feedback whilst in PWM mode).
22. **Robot-Lite *Buzz Board***- A cheaper ‘Robot Chassis’ which differs in that there are only 4 IR proximity detectors (immune to ambient light) which do not return a range value; there are no light followers (but line followers are still included) and the 2 gear-motors only work in PWM mode without feedback. 2 NiMH AA batteries are provided in place of the LI-ION battery but without on-board charging.
23. **Bluetooth *Buzz Board*** – This is a bluetooth device server targeted at applications that need a wireless serial connection. The specification is: Class 1 Bluetooth V2.0 compliant. Maximum range of 100 meters. It supports point-to-point and multi-point communications and uses an AT command set.
24. **GPRS *Buzz Board*** - a GPRS cellular phone modem with the following features: Class 10 Quad-

band GSM 850/900/1800/1900 MHz, packet data up to 85.6K bps, short message services, phone book management, fixed dialling numbers, RTC Alarm management, AT command interface.

25. **WiFi *Buzz Board*** - A Wi-Fi module that features: 802.11b/g compliant wireless networking, Wi-Fi security using WEP,WPA and WPA2, support for ad-hoc and infrastructure mode with a UFL antenna connector (antenna included) and AT command interface & updatable FLASH firmware.
26. **Range Finder *Buzz Board*** - This is a multichannel ultrasonic range finder that employs a unique synchronisation system, derived from an ‘Infrared Beacon’. Features include: 2 Channels per board, 2 Boards per ‘Processor Base Board’ plus 2 Extension sockets to allow two more ultrasonic range-finders to be fitted. The IR synchronisation system allows avoid interference when use for 1) Swarm behaviour interaction, 2) Robot to robot distance measurements, 3) Robot to beacon measurements, 4) Multiple robot operation in teaching labs. This module includes a through-bus for connecting to other *Buzz Boards*.
27. **Supplementary Range Finder *Buzz Board*** - This small extension board has an onboard extra ultrasonic range finder designed to provide all round ultrasonic vision for the robot. 2 ‘Range Finders’ can be fitted with 2 of these supplementary boards give the robot all round vision from 8 sensors.
28. **Infrared Beacon *Buzz Board*** - This beacon allows multiple Rangefinder Buzz Boards to be used in close proximity (same room) without interfering with each other (using synchronisation). This module requires a ‘Battery’ and ‘Inter-board Extension *Buzz Board*’. Note a future product will use this beacon for robot navigation using an IR scanner to obtain bearings.
29. **Battery *Buzz Board*** - This module is designed to support mobile and wearable systems. It’s features include a lithium-ion battery that charges from an external DC jack socket or USB socket.
30. **Test Point *Buzz Board*** – This module provides electrical access to all inter-board bus lines, allowing test equipment such as an oscilloscope to monitor signal behaviour on the bus. It also features Tricolour LED's on each pin which change colour depending on the signals state. This module has a through-bus enabling other *Buzz Boards* to be connected.