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Get connected to the Internet of Things

by John Beardmore, managing director, T4 Sustainability Ltd

What is it? First perhaps, we should ask what is the Internet? In a nutshell, the Internet is the network arising from the linking of devices using TCP/IP protocols. These are the protocols that allow the transmission and routing of packets of information across local area networks (LANs) and wide area networks (WANs). It is the ability to route packets between LANs via WANs that has perhaps made the biggest contribution to the success of TCP/IP as the dominant networking protocol in global use.

Which things? Well, anything really. Two traditional barriers to the networking everyday items has been the cost relative to the benefit gained, and difficulty of physically connecting to the net. These problems are dwindling rapidly as ICT costs fall and wireless WiFi becomes commonplace, so you can network your TV, washing machine or fridge.

Closely associated with the Internet of things are ideas like Smart Cities. I've seen a lot of exhibition stands proclaiming that smart cities will transform our lives, but I haven't seen many new or innovative types of project. On occasions I've wondered if the emperor has no clothes.

Many Smart Cities projects seem to focus on giving information about traffic congestion, public transport schedules, the availability of parking, energy billing and pollution monitoring. All worthy stuff; but these are hardly new ideas; what's changed perhaps is that implementation is now cheap enough that more cities, and institutions and companies within them, can undertake useful projects.

Also linked to the idea of Smart Cities is the idea of big data. Big data might be seen as very large diverse datasets which can be analysed to find meaning which is not apparent by looking at small amounts of data in isolation. In the context of Smart Cities, much of

this data is likely to come from the Internet of Things (IoT).

While individual datasets from IoT projects may not appear particularly exciting, it is perhaps the emergent opportunities to understand complex behaviours found through the analysis of big data that will in the end prove useful.

This gives rise to my first plea. If we are to be free to look for meaningful information within big datasets, access to this data needs to affordable and ideally free. There is a surprising amount of open data out there, check out the Open Data Institute[1].

Experience of the IoT

As members of the energy industry, our main interest is likely to focus on energy, and as a community we have some experience with IoT like technology in the form of environmental monitoring, automatic meter reading (AMR), building management systems (BMS), and Building Energy Management Systems (BEMS). Even if we haven't direct experience of installing these and setting them up, most of us with energy audit and opportunity assessment experience will have recommended them to clients with complex and ill-controlled heating and cooling needs, while perhaps feeling that while the suggestion has to be made, the client won't want to spend many tens or hundreds of thousands of pounds on such a system.

Where BMS has already been installed on a site, it's not uncommon to hear of problems. These include having capital funding to install the system but no revenue funding to maintain it; systems being installed but left on default settings; no in-house staff having any knowledge of the system; system now obsolete so can't be maintained or expanded; system now obsolete so modern laptops can't program it (wrong operating system, wrong physical ports).

The fact remains that BMS is still expensive. One example from my own work is the Galleries of Justice Museum in Nottingham. It's a listed building to which minimal energy-saving improvements can be made, which like many museums, struggles to break even, despite the contribution it makes to our education and culture.

The Galleries of Justice first

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installed a BMS around 2001, and it worked reasonably well. There was no funding for annual servicing and calibration however, and no staff had any knowledge of how to reconfigure it. Over time, the roles of some parts of the building changed, and some parts of the BMS system including the user interface had broken down by 2011, but most parts of the BMS carried on doing what they always had.

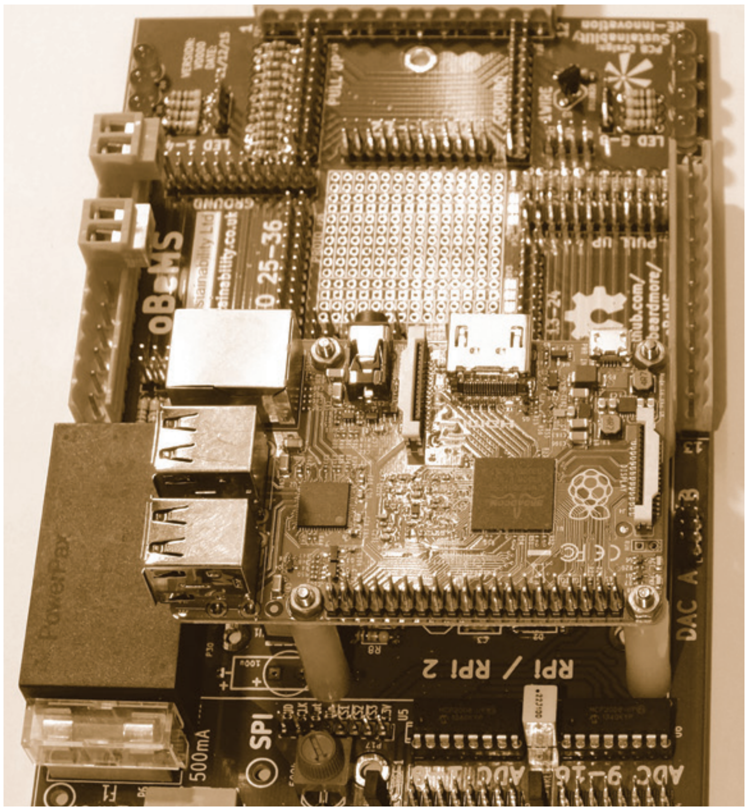
In 2015 we looked into restoring the BMS, but were told that it was obsolete, not least because the modern laptops used had no serial ports that could talk to the old BMS. While clearly there are other issues in play, it seemed to me that there was a desire on the part of the installers to start again. They offered a new system for £41,500 plus £3,300 per year for subsequent maintenance.

I sat down with the museum manager and we did a back of envelope calculation. If a new system costs, for example, £40,000 and lasts 20 years, a naïve calculation indicates that it might be seen as depreciating in value at a rate of £2,000 per year. In addition, there might be annual maintenance fees of say £3,000 per year. For the cost of such a BMS to be justified then, it has to save energy and staff time to the value of at least £5,000 per year. It is accepted that some of the benefits of BMS relate to environmental improvement, convenience, and other less tangible gains than money saved, but this is one of the perspectives from which a BMS purchasing decision should be evaluated. By our rough calculation the value of fuel and time saved by the use of a classic BMS would be on the order of half the cost of the BMS.

Of course, this rough calculation could be criticised. For example, fuel prices might rise over time, and the new system might not last twenty years (its predecessor didn't!) but there seemed to be little point in trying to finesse the calculation given how far the proposed system was from financial viability.

Cost of processing power

An article in The Economist[2] indicates that in the 1990s "the cost of a unit of computer processing power has fallen by 99 per cent over the decade" and "Over the past 30 years the price of computer processing power has declined by an annual average of 30 per cent in real terms; telecoms prices have been plunging at a similar pace over the past decade". Put less formally, the MIStupid[3] website recounts the old joke in which Bill Gates is alleged to say that "If GM had kept up with technology like the computer industry, we would all be driving $25.00 cars that got 1,000 miles to the gallon". I don't know whether Bill Gates really said this, but the joke makes the point well, that electronic revolution has massively reduced the cost and increased the functionality of most kinds of electronic equipment, and this trend shows no sign of slowing down.



Open source hardware designed to provide all the electronics for Raspberry Pi to operate in a BEMS

Given that the cost of most electronic equipment has fallen for decades, and energy prices have increased, I have to ask why BMS and energy management controls in general are still so expensive. One contributing factor might have been the dedicated wiring that was usually used, which had to run throughout the building. More recently however, it has become possible for elements of a BMS system to be linked by radio (including WiFi), as well as the hard-wired Ethernet of corporate LANs. Most equipment attached to a BMS still needs a power supply, but the rise of Power over Ethernet (PoE for short), has allowed the Ethernet cable to carry the necessary low voltage electrical supply in many situations. Another interesting trend is the rise of devices which use low power radio, which can harvest enough energy, from for example light or mechanical switch movement, to power their electronic and radio circuits. See the EnOcean web site for examples[4].

There are some promising developments in the array of commercial products. Honeywell Evohome deserves honourable mention as a lower cost control system which allows one set-point per zone, and one zone per room operation, with 'box on the wall' and web interfaces. Although intended as a domestic heating controller, there has been some success using this in larger buildings, by, for example, installing one system per floor. Although not the most flexible product (only one set-point, so no provision to control cooling for example), this sort of system might offer an intermediate price solution for the Galleries of Justice museum which could be viable, given that the primary requirement is to offer a well-zoned heating control system with a reasonable user interface.

So given the high cost of traditional BMS, and the inflexibility of many of the cheaper solutions, are there any other options which reflect the falling prices of ICT equipment and services?

The open source movement has made huge inroads over the last few years, gaining large market shares in many sectors, and delivering excellent tools and solutions in others. No doubt by now, everybody will have heard of the Linux and Android operating systems, and perhaps LibreOffice. Computer graphics aficionados may also have come across Gimp, Inkscape, Scribus and Blender; all highly recommended.

Open source solutions

So are there any open source AMR, BMS or BEMS solutions out there? Or can you make your own? And if you want to make your own, what constitutes a good system?

Open source options are starting to emerge. There isn't much out there if you go looking for BMS or BEMS solutions, but honourable mention in the UK must go to Open Energy Monitor[6] in Wales, who are building a growing range of energy monitoring tools based around low cost Atmel ATmega and Raspberry Pi Arm based computers[6]. Although there is a plethora of microcontroller platforms available, these two have led the charge in recent years, in delivering best productivity per pound spent to developers, and a great deal of community support and open source software is available to provide templates for project development on both of these platforms. The similarities and differences between them are instructive however.

The ATmega chips found for example on the various open source Arduino boards8 have small amounts of memory. The Atmega328 for example has 32 kilobytes of built in flash memory which is typically used for storing a program, and a mere 2 kilobytes of RAM memory, but has easily accessible timer/counters, interrupts, serial interface, digital input/output (I/O) pins, six analogue inputs, and watchdog timer. This simple environment can only run small programs, and network communication to other devices is limited, but for simple measurements which might depend on very precise timings, the Arduino products are hard to beat, and boards with this type of chip are available for a little as a few pounds. These don't have an operating system in the Windows or Linux sense, but do use various protocols for loading the program that will define the function of the chip.

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The Raspberry Pi comes in a number of versions. Pick the one which best meets your needs. Each uses a 'System On a Chip' (SOC) which has an impressive 512 megabytes of RAM, and gigabytes of flash memory accessible on low-cost interchangeable SD cards. Again there are timers, interrupts, a serial interface, digital I/O and a watchdog timer, but no analogue I/O. This allows the loading of large and complex operating systems, which in turn allows the running of many tasks at once, with access to the Internet over wired Ethernet or WiFi. Because access to the hardware is controlled by the kernel of the operating system, it is not as easy to directly exploit the system hardware as it is with ATmega based systems, though the Pi can be used with additional external chips, or Arduino[8] systems, to provide these facilities.

It isn't uncommon to see designs in which these two types of system together, the ATmega side providing very precisely timed operations and analogue data, and the Pi providing much more processing power, user interface, and network connectivity.

A lot of open source work has also been done in the home automation sector which tends to focus on heating controls, lighting, appliances, media systems and security. Some examples can be seen online[5]. While these are not necessarily what you'd want in a BMS system, some of the systems might form a starting point for other projects. A Greek company, Plegma Labs[7] has developed solutions from the openHAB code base. Plegma is also interested in developing ways for existing building automation products to interoperate.

Make your own automation

The lesson from these systems (and some personal history in software development) is that you can make your own building automation systems, and conceptually it isn't very hard. The fundamental algorithms in most BMS systems needn't be particularly complex; there is probably more to learn about communications and the interfaces if you want what you develop to be easy to use.

So for an AMR or BMS system, what constitutes good design?

Well, the system needs to scalable, modular and flexible, so it can be deployed on any scale from a single computer with perhaps a simple web based interface to view recorded data, to a system consisting of a network of many such machine, each taking measurements and / or controlling equipment, with user interfaces to allow effective control, and logging of activities to allow analysis and optimisation of behaviour. All such systems need to be set up to allow high system availability and reliability. These requirements give rise to some approaches which might not be adopted by the typical amateur enthusiast, who are not used to working with machines that are left to function for years at a time without human intervention.

All computer systems crash from time to time. Yours are unlikely to be an exception. In a system which controls critical equipment, the important thing is not so much ensuring that it can never crash under any circumstances, as making sure that when it does crash, it recovers quickly, and resumes its normal function with minimal loss of data and control. The idea of a watchdog timer, is to monitor the activities which should normally be occurring, and restart the system if they are not.

This can be achieved either using software or hardware, but with software watchdog timers, there is always some risk that the machine will crash before the watchdog is initialised, so reset never occurs; hardware watchdogs have an edge. Allowing a machine with a complex operating system like Linux or Windows to be reset without a proper shutdown tends to corrupt the flash memory where the operating system and programs are stored, so the use of watchdog while necessary, is not sufficient to deliver the necessary reliability.

Corruption of the card

Two issues which bedevil systems which boot from SD cards are corruption of the card if the system crashes or is shutdown incorrectly, and failure of the card caused over time by repeated rewriting of parts of the flash memory. The simple solution is to run the system with the flash memory accessed as a read only device. Ideally it should only be written to during development work, and all logged data should be written to RAM for short term local use, or over networks to machines with conventional magnetic disks for archive use. (A compromise is to add a second flash drive to the machine which is only has data written to it perhaps for a few seconds or minutes every hour. This increases the likely life of the SD card compared to writing small amounts of data, perhaps every minute.)

To meet our own needs, and I've decided to make this an open source project, I've developed a number of software modules (servers) which act as modular programs to offer interfaces to physical sensors and actuators, with other programs (clients) which interact with the real world via the server processes. Because these programs talk to each other over the network, the needn't all run on the same machine, and the machines they run on can be located anywhere.

To accompany this software we've designed a board, open source hardware this time, which is intended to provide all the supporting electronics that a Raspberry Pi usually needs to function in an AMR, BMS or BEMS application, including various power supply configurations, a hardware watchdog timer, analogue and digital I/O, a prototyping area to meet bespoke needs, and connectors to make it as easy as possible to link the system to external wiring.

Together this software and hardware forms a useful template for all sorts of IoT projects, though my emphasis has been on energy measurement. Some introductory information about this is available on the net[9]. I hope it will evolve over time, from a fairly basic AMR tool, to a flexible open source BMS.

If you're going to release open source materials, it's sensible to pick one of the standard open source licences. These are boring but important reading, as the license you pick will determine who can use your work, and how they can use it. Many websites offer guidance on this[10], but there is no substitute for reading the licenses and seeking legal advice if necessary.

It's impossible to go into the details of IoT development in a single article, but I expect I'm not alone in starting to develop IoT projects. I'm going to suggest then, that anyone who's interested in this field might contact me, and we might establish an online forum to allow discussion of these issues and the support of each other's work. If you're interested, please email me as John@T4sLtd.co.uk

The Galleries of Justice Museum in Nottingham where a new BEMS would have cost over £41,000

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CPD SERIES **14** | MODULE **05** | OCTOBER **2016**

ENTRY FORM

THE INTERNET OF THINGS

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

QUESTIONS

1. **Why did TCP/IP overtake other network protocols and become dominant?**
   - ☐ Price
   - ☐ Simple and compact protocol stack
   - ☐ Use of packets for sending messages
   - ☐ The ability to route messages between local area networks using wide area networks

2. **During the 1990s, how much did the cost of a unit of computer power fall?**
   - ☐ A factor of ten
   - ☐ A factor of thirty
   - ☐ A factor of a hundred
   - ☐ A factor of three hundred

3. **In the general case, how would you expect IoT devices connected to the Internet?**
   - ☐ Dedicated wiring
   - ☐ Any link capable of sending IP packets to a LAN or WAN
   - ☐ A radio link
   - ☐ A 10BASE-T cable.

4. **What does PoE simplify?**
   - ☐ The provision of power to devices connected to wired Ethernet
   - ☐ The implementation of structured cabling systems
   - ☐ The connection of routers to telecommunication systems
   - ☐ The wiring of CAT V connectors

5. **Which source of energy would not be used in an energy harvesting sensor? (Clue, look at the range of products on the Enocean website.)**
   - ☐ Heat from pipework
   - ☐ Light
   - ☐ Lithium iron phosphate battery
   - ☐ Electromagnetic field around a cable

6. **Is open source material**
   - ☐ Restricted to hardware development
   - ☐ Governed by a range of binding and enforceable license options
   - ☐ Restricted to software development
   - ☐ The giving away of intellectual property without restriction

7. **Which feature would you not expect to need to add to microcontroller board (e.g. an Arduino or Raspberry Pi) if you needed it for a project?**
   - ☐ Power supply
   - ☐ Digital to analogue converter
   - ☐ Digital I/O connections
   - ☐ Serial interface

8. **What feature protects the operating system, system configuration, and programs installed on a system in the event of a crash?**
   - ☐ Appropriate timeouts on network operations
   - ☐ Keeping core dumps for analysis
   - ☐ Minimising the number of files open at any given time
   - ☐ The use of a read only file systems

9. **What level of reliability is achievable in an IoT system in normal use?**
   - ☐ The system should restart automatically if it fails
   - ☐ It should never fail
   - ☐ Reboot every three weeks
   - ☐ Reboot every three months

10. **What offers the ultimate guard against system failure?**
    - ☐ The prevention of resource leaks
    - ☐ The use of assert statements
    - ☐ The watchdog timer
    - ☐ Respawning failed processes

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