Control Systems and the Internet of Things – Shrinking the Factory

Dr. Edward Smith
British Telecom,
Adastral Park,
Ipswich, UK
edward.a.smith@btinternet.com

Luke Fuller
Z-Tech, Unit 4 Meridian,
Buckingway Business Park,
Anderson Road, Swavesey
Cambridge
CB24 4AE
Luke.Fuller@z-tech.co.uk

***Abstract*— In this paper we discuss the Internet of Things (IoT) by exploring aspects which go beyond the proliferation of devices and information enabled by: the growth of the Internet, increased miniaturization, prolonged battery life and an IT literate user base. We highlight the role of feedback mechanisms and illustrate this with reference to implemented computer enabled factory control systems.**

As the technology has developed, the cost of computing has reduced drastically, programming interfaces have improved, sensors are simpler and more cost effective and high performance communications across a wide area are readily available. We illustrate this by considering an application based on the Raspberry Pi, which is a low cost, small, programmable and network capable computer based on a powerful ARM processor with a programmable I/O interface, which can provide access to sensors (and other devices). The prototype application running on this platform can sense the presence of human being, using inexpensive passive infrared detectors. This can be used to monitor the activity of vulnerable adults, logging the results to a central server using a domestic Internet solution over a Wireless LAN.

Whilst this demonstrates the potential for the use of such control/monitoring systems, practical systems spanning thousands of sites will be more complex to deliver and will have more stringent data processing and management demands and security requirements. We will discuss these concepts in the context of delivery of a smart interconnected society.

Keywords-component; Control Loop; Factory System; Interfaces; Internet of Things; Radio network; Sensor network.

I. Introduction

The Internet of Things (IoT) is more than the proliferation of devices and information enabled by the growth of the Internet, increased miniaturization, prolonged battery lives and an ever more IT literate user base. The real benefits may well be released by closed loop control systems and open loop monitoring systems. The idea of controlling processes using computers and communications has been around for some time and an early manifestation of this was factory control systems. Modern technology greatly improves the potential for deploying these solutions; however the complexity of data management and security concerns [1] together with the complexity of roll out, can hold back deployment.

IoT is often thought to be concerned with the combination of Information and Communications Technologies (ICT) to control devices. The area is expected to grow rapidly, with Gartner suggesting that 6.4 billion connected devices would be used across the world by 2016, reaching 20.8 billion by 2020. This technology was expected to support a total services spend of $235 billion in 2016 [2]. Garner also show how deployment is likely to proceed, as referenced by their hype cycle. [3] They see IoT platforms as being 5-10 years away from mainstream adoption and just making the transition from technology trigger to the peak of inflated expectations [4].

Davies et al [5] suggest that technically, there is little fundamentally new in IoT and that novelty arises out of working on an increased: numbers of devices, quantity of data, scope for automation and the potential for information sharing. We'll support this assertion and show that the IoT can be considered as an extension of the remote systems used in factories for well over 35 years. We will also explain how modern technologies have provided cheaper: networking, processors and components and this coupled with advances in tooling and application based communications have accelerated progress. The reduction in power consumed by and size of sensors has also played its part.

This paper will begin giving a technology based overview of a factory system from the late 1970s and highlight some of the key capabilities and functions. This will lead to us discussing the technology drivers that make this more feasible with today's technology and examine how this can be implemented using a simple use case known as "The Marauder's Map". We will compare the factory systems and Marauder's Map to emphasize what the changes are. We conclude by considering the complexity of wider roll outs.

II. Factory Systems

We begin by describing two factory systems than were operation at United Biscuits in the late 1970s, the Harlesden Factory System and the Crisp Weight Control system, which operated on crisp production lines in Grimsby, Ashby de la Zouch and Teesside. The systems were based on DEC PDP 11 computers, which interfaced to factory machines interfaces using GEC Media interfaces. The PDP 11s used were able to run a factory on 32K words of memory (16 bit word) holding data on 2.5 MB discs.

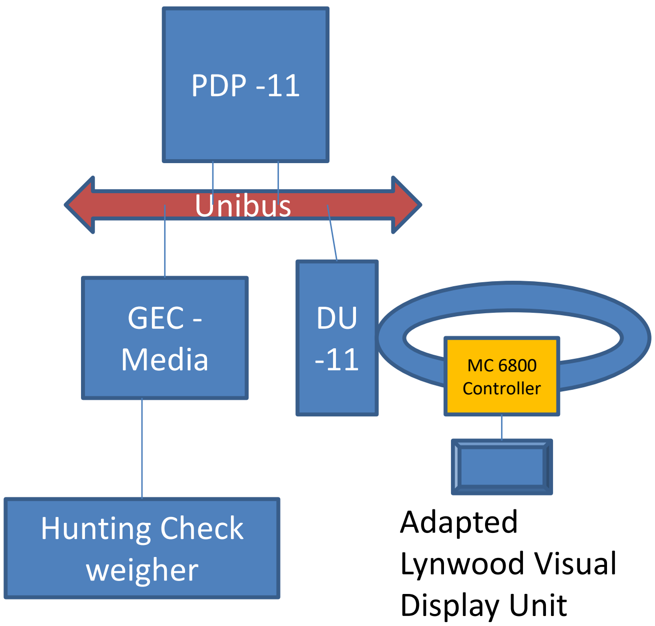

Figure 1 The Harlesden Loop

Figure 1, shows the Harlesden biscuit factory configuration for production monitoring, which was known as the Harlesden loop. The terminals were adapted Lynwood visual display units, with key boards replaced with single function keys and a numeric key pad, to make life simpler for the factory floor workers. A Motorola MC-6800 based controller was used to translate the terminal data into standard ASCII key strokes and gather factory information from a number of badge reader devices. The badge readers allowed factory operatives to report production line status to the system using pre-punched status cards or badges, again minimizing the need for operator input. The Motorola based controller also provided an interface to a Cambridge Ring style LAN [6], which interfaced to applications on the PDP-11 using a DU-11 synchronous interface.

The GEC Media system provided a "memory mapped " interface to factory plant and could handle binary digital inputs and outputs to and from factory plant and convert the analogue output from the check-weigher devices to digital input required by PDP-11. This memory mapped access required the software to regularly check the condition of the changing memory locations, but avoided the need for interrupt driven I/O.

The system could be used to manage and record biscuit packet weights to ensure adherence to tolerances and to reject underweight packets, to keep goods sold within the legal, stated product weights. The system could also be used to manage the current status of factory plant, identify when there were issues and monitor repair progress. It also provided a means of recording raw material waste and managed efficient use of raw materials. Applications were programmed in either RTL/2, a C like high level language or Macro 11, the PDP-11 assembler language.

The specialist terminal, Cambridge Ring and Motorola based controller technology were not used by the Crisp Weight control systems, which are shown in figure 2 below.

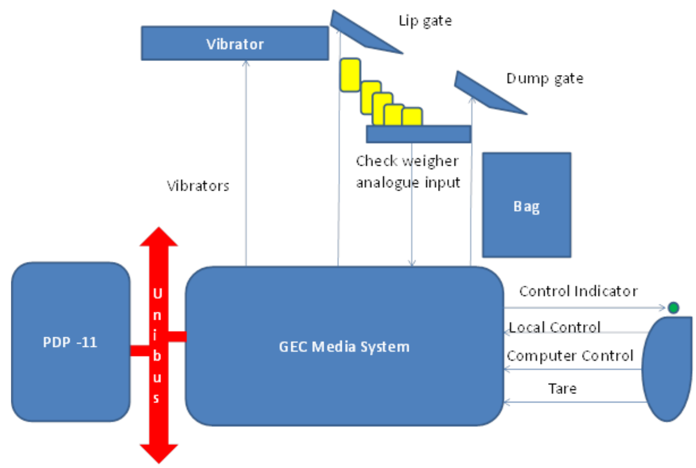

Figure 2 – Schematic for the Crisp Weight Control system

The system could typically control up to 72 crisp bagging machines, which were typically arranged in lines of 30 or so machines, with each production line potentially handling a different product. Crisps were directed via vibrating channels towards a weigh pan, access to this was controlled by opening and closing a hinged lip gate. A second gate known as the dump gate stopped the crisps from falling from the weigh pan into a bag. The machine itself could be in one of three states: under local control, under computer control and tare (calibration); all enabled through a physical switch. Once a machine had been switched to computer control, this would activate a digital input (a single bit state sent from the machine to the computer) on the Media system, when the computer had detected this and accepted control of the machine it turned on an indicator light on the machine. The crisps weight was detected when the weigh pan sent an analogue signal towards the computer and this is converted into a digital form by the Media system.

Digital inputs indicated when a tare operation was in progress, and whether the machine was under local or computer control. By manipulating a single bit in a memory word (digital output), the computer could cause the Media system to: open or close the lip gate, start or stop the vibrators, open or close the dump gate or turn the computer control lamp on or off. The Media system also performed analogue to digital conversion, allowing the analogue output from the weigh pan to be read into a word of PDP-11 memory, allowing the system to monitor the weight of crisps in the pan.

The objective was to ensure that bags of crisps met the minimum weight specification, without making too many overweight bags; that is unnecessarily giving away product. The cycle began when the computer activated the vibrators, opened the lip gate and closed the dump gate to allow crisps to pass onto weighing pan. The computer continually monitored the output from the weighing pan and once it detected that minimum weight had been reached it stopped the vibrators, closed the lip gate and opened the dump gate. This allowed the crisps to fall into the bag and the bag to be sealed.

Some crisps would still be "in-flight", between the lip-gate and weigh pan, when the minimum weight is detected and the lip gate is closed. This would result in overweight bags being produced. To prevent this eventuality, the computer recorded and tracked the weight of crisps accumulating in the weigh pan and statistically estimated the weight of the inflight crisps, closing the lip-gate when the sum of the weight of the crisps in the pan and "in-flight" reached minimum weight. If the computer overestimated the weight of the "in-flight" crisps then it could reactivate the vibrators and open the lip gate, to top up the bag, before re-closing the lip gate and activating the dump gate.

Once the crisps have been bagged, then the dump gate could be closed, the vibrators activated and the lip gate opened to fill another bag.

The systems also required software to set up the machine for a specific product, provide production reporting and to monitor the performance of individual weighing machines. All programming was done using the Macro-11 assembly language.

Having considered the principles of the cooperation of sensors, networks and computers to deliver a control/monitoring loop; we now examine what advances in technology have to offer through discussion of a prototype implementation.

III. THE MARAUDER'S MAP

Since the 1970's the cost of computing has reduced drastically and high performance communications across a wide area are readily available. In addition, programming interfaces have simplified, with much lower dependence on assembler level programming. In addition, the potential of automation to improve process, together with an appreciation of some of the draw backs, have become more widely appreciated, as the general public are much more familiar with computers. In addition the electronics have become simpler and more cost effective, as we will demonstrate through the next application the Marauder's Map.

The Marauder's Map is a simple but effective prototype application written in Python running on a Raspberry Pi computer (readers of the Harry Potter series will recognize the origins of the name). The Raspberry Pi [7] is a small €35 device of the type present in many Smartphones and is based on powerful ARM processor. It is a fully programmable device and has built in communications capabilities, although the Wireless LAN interface is a modestly priced add-on. The device has limited storage and runs a version of the Linux operating system. It also has an onboard programmable I/O (PIO) interface to provide access to sensors (and other devices).

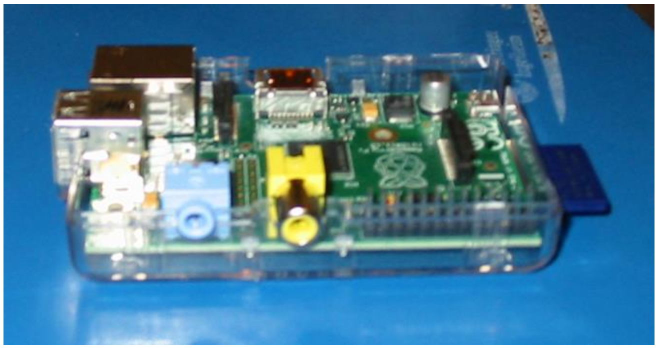

Figure 3 The Raspberry Pi

The prototype uses a pair of passive infrared detectors, connected to the PIO chip using a wired interface. Their role is to identify the presence of human beings in a house through detection of their body heat. This allows the remote monitoring of activity of vulnerable adults. Communications to the outside world is achieved using a domestic Internet solution over a Wireless LAN. Status messages generated by the Raspberry Pi, when a signal is received from the PIR, are uploaded to server on the Internet via a standard domestic broadband service. The current prototype restricted to a single home and is shown in figure 4 below:

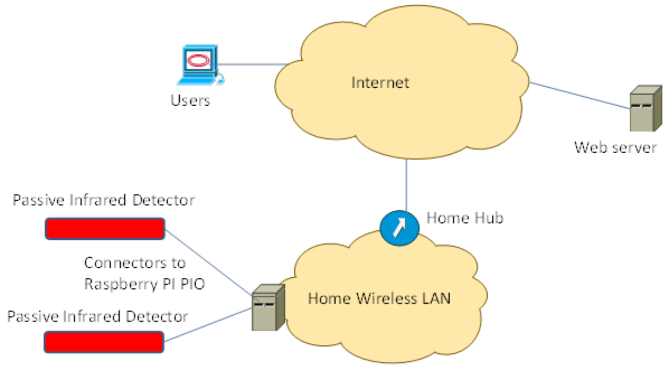

Figure 4: The wider Marauder's Map System

The web server collects the messages from the Pi, stores them and generates a visual graphical output, which has immediate impact and is shown in figure 5. The output can be accessed from any browser enabled device, including a Smartphone. The use of the Internet makes the location of observer irrelevant. The current prototype shows activity in two locations in the house.

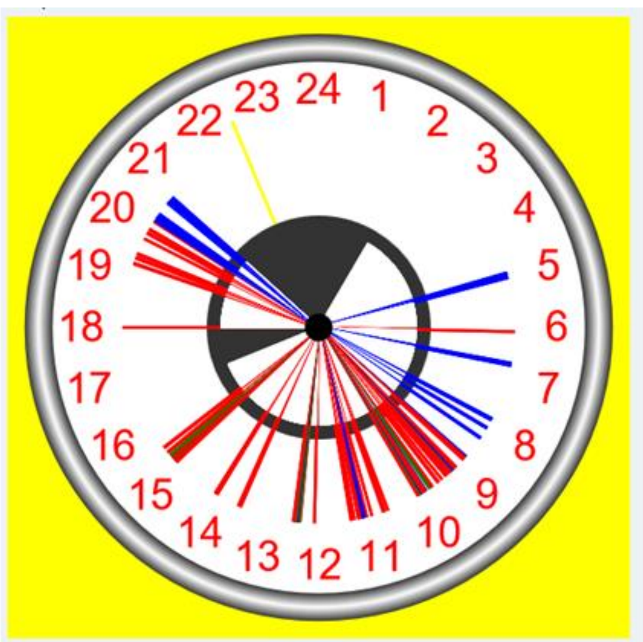

Figure 5 – Marauder's Map output, data from each sensor is color coded.

Having examined how modern technology can implement an "open-loop" monitoring system, we now move onto examine the differences between the systems already described and how modern technology has created new opportunities and challenges. This will allow us to consider the move from the factory environment to wider use.

IV. System Comparison

The original factory system took man years of effort from a multi-skilled team and required the use of specialist equipment costing many hundreds of thousands of pounds. In addition the interface between the factory plant and computer system was highly specialized and expensive. All the intelligence was in the central computer and communications capability was constrained to the factory. In some cases modem access was possible, but the mechanism for answering the phone required direct access of the communications interface board connected to the modem, allowing explicit checking, coordinating and setting of the modem signals. This was much more low level than the Hayes protocols that many readers will have used.

All the computational effort had to be managed by the PDP and to minimize the storage used and optimize processor performance assembler level programming was used. The PDP not only had to manage the industrial process, it also had to handle reporting within factory and important functions such as product changes. Reporting by its nature was in tabular rather than graphical format.

The Marauder's Map in contrast was built in a short time by one individual, based on Open Source software and using generally available equipment from Amazon, at a total cost less than €100. The intelligence available in the Raspberry Pi allows the monitoring of the sensors to be managed locally, with only key information being passed to the central server which manages and displays the important data. The Raspberry Pi itself is driven by Python scripting, which is considerably simpler for development than assembly language. Communications are greatly simplified through use of Wi-Fi within the home and data communications using a standard broadband connection. This technology enables the use of location independent graphical reporting across the Internet.

However we would note that the current implementation is a simple but effective prototype, which would require considerable development for serious deployment. It demonstrates what is possible and we would argue the essence of the Internet of Things. In practice remote deployment of remote sensor based systems such as this is complex.

There have been a number of proposals for describing the architecture of IoT systems. Newstead [8] considers three overlapping ideas: Machine to Machine communications, which he considers as a subset of the IoT, the IoT itself and a related high level representation known as Cyber Physical Systems [9]. The latter provides a five layered model, maps the physical characteristics of an intelligent entity to its virtual representation in the control environment. Newstead maps this onto a four level model of Device, Connectivity, Application and Analysis. The device is the entity being controlled, connectivity is divided into network access and fixed line and the application is the interface that allows management. Analysis includes the capture, storage, aggregation and utilization of the data, as well as the actual data analysis. An alternative physical model, comprising of five tiers has been proposed by Fisher and Davies [10] consisting of a sensing layer, gateway and connectivity layer, data storage and exchange, big data analytics and applications. It can readily be seen that the factory systems and Marauder's Map applications we have described resemble the architectures described by Newstead and by Fisher and Davies.

We now consider some additional technological opportunities and challenges; that lie on the path towards the Internet of Things.

V. TOWARDS THE INTERNET OF THINGS

The drivers for adoption of the IoT are seen as: falling costs, social changes, maturity of information sharing, managing complexity and technological readiness [10].

Complexity and cost comes from the requirement to roll out solutions across thousands of sites and this generates the requirement for strong project management. The data processing and data management demands on such solutions are considerably greater than are managed by the prototype. Accordingly the security concerns can be complex and these have been widely discussed in the literature [1]. Also IoT solutions are delivered through complex ecosystems, for example the UK Smart Metering solution is an example of this [11]. Further the number of customer stakeholders is large, producing wider requirements demands.

Historically, industrial monitoring, control and manufacturing processes are referred to as supervisory control and data acquisition (SCADA). Increasingly radio communications are replacing wired communications in these systems. The key radio standards identified are IEEE 802.15.4, which offers low data rates and operates in the ISM (Industrial Scientific and Medical) bands, Bluetooth and IPv6LowPAN, which provides standards to translate and compress IPv6 headers for 802.15.4 packet sizes [12].

ZigBee and Z-Wave are low power and low bandwidth and often need a bridging device to connect these to an IP network. Z-Wave is proprietary and offers tightly controlled device interoperability from a limited number of chip suppliers. It's likely that the industry will move towards cheap to implement IP based connectivity, which is likely to attract significant marketing effort [13]. Table 1 summarizes the key technologies and their capabilities.

	Frequency	Data rate	Range	Topology
Z-Wave	868 MHz	100 k bps	about 30m	Star
ZigBee	2.4 KHz, 868 MHz	250 kbps	10-100m	Mesh
Bluetooth Smart	2.4 GHz	1 Mbps	100m	Star/Mesh
DECT ULE	1880-1900 MHZ	1 Mbps	300m	Star
802.11ah	Sub 1 KHz	40 Mbps	<1km	Star
Thread	2.4 KHz, 868 MHz	250 k bps	10-100m	Mesh
6LowPAN	2.4 KHz, 868 MHz	200 kbps	10-100m	Mesh

Table 1: Summary of the principal radio technologies likely to be deployed in IoT Solutions

Much is made of the fact that IoT applications have low data throughput and integrity requirements. A distinction can be made between two types of application: connected cars and autonomous vehicles that need high bandwidth, secure, low latency networks; and less intensive applications, which will send less data, infrequently and which will tolerate a lower service quality and throughput. An ideal Low Power Wide Area network would have: long range (15-20km), support for millions of nodes, long battery life in excess of 10 years, very low cost and globally available radio frequencies in a narrow band. LTE is considered to be the best route for high bandwidth devices [14].

There is no fundamental obstacle to the adoption of IoT, but hindrances are the multiplicity of standards at every level of the stack and limitations at the higher levels due to the lack of a common naming standard to facilitate data sharing between services. These restrictions on interoperability could be overcome by the development of an automated way for IoT clients to discover data they can understand in any IoT service [15]. This is a focus of the Hypercat consortium [16].

Having identified these factors it is clear that the systems we have described demonstrate some key aspects of the Internet of Things. The obvious similarity is the use of real time feedback systems and solutions built on IT and communications systems. Both cases required detailed comprehension of the process or system being managed, understanding the requirements in as much detail as the technology. The key enablers of these solutions are sensor and control interfaces to an IT system. As well as the direct interfaces to plant, there is a strong requirement for accurate reporting and data management.

The systems described demonstrate that the interaction of the interworking of the software and hardware components is critical. It should be noted that, whilst the use of IP protocols for communications is expected to be common (indeed advised) it is by no means a mandatory feature.

VI. CONCLUSIONS

The idea of controlling processes using computers and communications has been around for some time and an early manifestation of this was factory control systems. We have shown that the technologies employed in factory systems are of direct relevance to the IoT problem space. Further we have described how modern technology greatly improves the potential for deploying these solutions by referencing the Marauder's Map use case. However the complexity of data management and security concerns together with the complexity of roll out can hold back deployment. There are signs that these issues are being addressed so that these solutions can ultimately deliver the considerable benefits, they offer.

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