EMBEDDED INTERNET SYSTEMS: APPLICATIONS IN CONSTRUCTION

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ABSTRACT

This purpose of this paper is to explore developments in Internet communications technology on site. In particular, the paper examines the role of 'stand alone' or embedded systems in the context of a *lean* approach. These low cost devices are capable of reporting and receiving information in just the same way that computers on a network can. The advent of a new Internet communication standard, TCP/IP 6, offers significant potential in terms of remote monitoring and management of construction sites using embedded systems. In the discussion, the author considers the technological issues involved and the implications for management on site.

KEY WORDS

Embedded systems; TCP/IP; protocols; networks; lean construction.

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INTRODUCTION

Industry analysts see embedded Internet systems as poised for rapid growth in the manufacturing sector in the next few years. To date, much of the research work pertaining to the Internet in construction, has focused on person to person, or computer to computer communication. Embedded Internet systems allow users to communicate with other items such as plant, machinery, and manufactured components delivered to site. This communication may range from passive remote monitoring to direct control or resetting. What significance does this have for lean construction?

LEAN PERSPECTIVE

From the lean thinking perspective, embedded systems offer the opportunity to migrate from the batch-and-queue approach used in construction to the *flow* approach espoused by Womak and Jones (1996). Information is able to migrate with a component or resource as it is transformed or used in the construction process.

Taiichi Ono (1912-1990), in his description of *muda* or waste, identified several areas of activity which consume resources but contribute no value, each of which can be seen in the construction context:

- Mistakes which require rectifying (reworking)
- Production of unwanted goods (surplus materials on site; spoilage; theft)
- Unnecessary process steps
- Unnecessary movement of goods and people
- Idle time of people waiting for the completion of an upstream activity

Each of these forms of waste can largely be attributed to the absence or loss of information. Electronic labelling provides a way of enabling a flow process, whilst providing information on site level. The synergy between electronic tracking and global addressing provided through the Internet brings another dimension to this flow process. In the words of Ian Douglas Agranat, founder and CEO of Agranat Systems Inc:

> *"It won't be long before intelligent devices worldwide will be nodes on a network and managed from Web browsers."*

EMBEDDED SYSTEMS AS LABELS

Embedded systems contain a computer or a computer-like device that is used to control the operation of plant, machinery and equipment. They have proven very useful and commercially successful in the manufacturing sector but have been little used in construction, partly because of the temporary and itinerant nature of the construction process. Embedded systems are found in engineering tools and process control systems. They are increasingly used in office and consumer products, such as cars, washing machines, photocopiers and bedside alarm clocks. The continued fall in cost of these devices, now justifies their use on disposable items.

Embedded chips present an alternative to bar coding as a method of electronically labelling materials, machinery and personnel on construction sites. The potential benefits of bar-coding in construction have been addressed by various authors including Bell and McCullouch (1988), and Finch, Flanagan, and Marsh (1996).

The next step in the evolution of labelling technology, suggests that ink-on-paper bar codes will be surpassed by embedded chips. The chip becomes the label that can serve as a standalone data base. Attached to an object or carried by a person, the chip identifies and carries relevant information available instantly with little or no human intervention.

Three distinct limitations of bar codes are overcome by chips:

- Chips hold significantly more information
- Information on the chip can easily be updated via computer while affixed to their object.
- Cost of access points, that is the communication with computers, is drastically lower because of direct, chip-to-chip digital data transfers.

One example of a robust embedded system suitable for construction environment is the iButtons patented by Dallas Semiconductor Corp. With iButtons, the chips are housed in a stainless steel container (known as a MicroCan) which serves two purposes: (1) electrical contact and (2) protection of the chip from the environment. Each iButton proves its identity by its unique registration number. The contents of the iButton can be changed while attached to an object. Unlike bar codes, these labels can be read or written without expensive electro-optical equipment. These devices find applications as re-writeable data carriers in many market segments such as:

- Access control
- Personal identification
- Time/attendance control
- Asset management
- Off-site and on-site manufacturing
- Commissioning

These devices also serve as electronic labels, storing manufacturing history, revision status, and other important information on products to which they are attached.

INTERNET ENABLED

Conventional embedded systems require intervention at a site level to obtain information. In the case of the iButton this is achieved either by direct physical contact with a metallic surface, which in turn can be connected to a local low cost local area network (LAN) or transferred directly to a data logger or computer.

The accessibility of this information is significantly curtailed by this need for proximity. However, developments in the Internet protocol, TCP/IP, which is the universal communication standard, looks set to change all of this. The Internet was originally designed to cope with a limited number of computers and users worldwide. In order to allow communications to be directed, every physical location on the Internet (server or client) requires an address. However, the current system, TCP/IP version 4 (known as IPv4) is becoming increasingly strained by the limited size of its addressing system which is 32-bits in size. The Internet, if it remains with this system, will eventually run out of numbers. If we are to include not only computers but embedded systems in our network, scarcity of addresses becomes a major limiting factor. The transition period between the two versions is likely to extend over a decade. Therefore, much effort is being consumed in ensuring that the new version is interoperable with the existing standard to allow upward migration.

Until now, the Internet has served almost exclusively the computer market. With the introduction of IPv6, the Internet is likely to serve very different needs in construction, each with a new set of requirements. Nomadic computing, through a variety of network attachments including radio frequency wireless networks and infrared systems, will make on-site communication more viable. But perhaps more significant will be the possibility of remote device controls—more specifically embedded systems.

As well as a standard communication language, the Internet has recently acquired a universal standard for portable software encoding, known as Java. Mulchandani (1998) describes a high-level overview of different issues surrounding embedded Java. As the Internet gains popularity, many consumers will look to Java as a means to access services and content. In its present form, the Java platform does not currently fit well in the requirements of embedded systems based on the size, performance requirements, and other technical issues. Mulchandani (1998) describes work currently underway to overcome these shortcomings.

APPLICATIONS OF EMBEDDED INTERNET SYSTEMS

Possible applications of Internet enabled embedded systems include:

- Remote checking of strain gauges; temperature and weather conditions; light conditions from the civil engineers office
- Remote observation of site progress by the project manager or client using Internet controlled cameras
- Remote calibration, system optimisation and monitoring of heating, air conditioning and ventilation equipment
- Remote tracking of personnel, plant, machinery and materials

However, these applications should not be seen in isolation. Addressable device controls and electronic labels should form part of a holistic system consistent with the lean approach. This means considering issues of value. The information derived from electronic monitoring should not be seen as an end in itself. Perhaps the most important benefit to lean construction is the *transparency* it brings to the flow of processes. What happens to a product as it passes through manufacturers, suppliers, subcontractors and eventually to the building manager and user. Only by having this transparency is it possible to pursue *kaizen*, or continuous improvement. Unnecessary processes become opaque, idle time becomes vividly clear and materials wastage is less easily dismissed as an inevitable outcome.

OTHER INDUSTRIES

A partnership of hardware and software developers, TEK Communications and Diversified Systems Group developed an embedded touch memory technology to help the United States Postal Service improve efficiency in its collection and delivery systems. Inside the door of every blue postal box standing on curbs across America, an embedded button device has replaced the almost illegible bar code that formerly identified the box. Being more than a digital box address, however, the button is also a sentinel clock and calendar for the carrier making the daily rounds through rain, sleet and snow. When picking up mail, the carrier touches the iButton with a 40Kpen-sized reader, storing a digital log of the pick-up location, date and time. Back at the post office, the carrier touch-downloads the data to a central station. Management then uses the day-to-day tracking to assess the efficiency of route layout and box placement. The digital record also proves carrier performance, benefiting both carrier and manager while optimizing delivery of the U.S. mail.

Internet technology is also forming part of embedded systems in power engineering allowing remote access to such systems. Described by Itschner (1998) *et al*, remote access is enabling cost savings in development, commissioning, use, and maintenance are the major driving forces for transferring Internet mass technologies from the office and commercial sectors to industrial applications. The GLASS system provides remote monitoring capabilities to a large range of industrial facilities, from "unmanned substations to large plants or devices on mobile platforms like trains or ships. GLASS uses off-the-shelf technology and products wherever possible. An unlimited variety of devices can be accessed and combined through Java-based intelligent proxies. Remote monitoring with global access through the world-wide Internet opens new service business opportunities and the foundation for cost-effective just-in-time maintenance."

INTERNET ENABLED BUILDING MANAGEMENT SYSTEMS

The idea of a fully networked and integrated building management system is nothing new. Several rival protocols have evolved including BACnet and LonWorks that allow individual sensors and services to cooperate over a common building network so that disparate systems such as emergency lighting and heating can operate in unison. These systems provide tremendous benefit in terms of saved wiring, decreased integration costs, and increased system flexibility. Many automation systems however have additional requirements that go beyond the scope of the fieldbus solution. These requirements include: (1) remote access to the network for monitoring, diagnostics, network management; (2) linking of disparate fieldbus subnets; (3) access to the fieldbus control network from the enterprise LAN.

The online White Paper produced by Gaw (1997) describes the technical issues involved in transforming a local building management system operating on a LonWorks protocol to a globally accessible system.

Consistent with the lean approach of *flow*, there is an argument that building management systems should not be divorced from the idea of an electronic construction management system. A system which is driven by a collection of devices capable of operating independently, accessible remotely, and able to provide corporate wide information. From the client's view, there may be a case for blurring the edges between the network installed in the finished building and the network used to bring it into being.

CONCLUSIONS

This paper has attempted to highlight the opportunities that have arisen due to innovations in embedded system technology and Internet communications. The synergy between the two is likely to offer up more than the sum of its parts. In order to derive benefit from this synergy, construction projects must take a broader view of asset tracking and monitoring. Much of the *muda* evident in construction arises at the interface between contractors, clients and designers. Exploiting embedded Internet technology will require a project wide strategy that embraces all parties and considers in detail the value imparted to the client.

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