EMBEDDED-INTERNET DEVICES: A MEANS OF REALIZING THE PERVASIVE COMPUTING VISION

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ABSTRACT

This paper explores the feasibility of applying newly emerging low-cost embedded-Internet devices in support of pervasive computing; a new vision whereby domestic appliances are provided with Internet connections enabling them to be accessed and controlled from anywhere, anytime, via any web based interface.

The principal challenges addressed by this work were how to design an embedded-Internet computing architecture that supported appliance control, multimode heterogeneous clients interfacing and mixed wired and wireless communication.

We present a generic architectural solution for the design of Internet appliances. We show how this can be realised by describing a practical implementation based around a novel, “botanical plant care” embedded-Internet appliance. In this the server-side utilised a Dallas Semiconductors TINI embedded-Internet device, as this product typified the available off-the-shelf technology. The client side was based around PCs, PDAs and mobile phones using Web and WAP interfaces. The communication mediums were wired-IP, WiFi and Bluetooth. The choice of these technologies was driven by their widespread public use which is leading them to become the de-facto standards in this area.

From this work we show that it is feasible to use the new generation of low-cost embedded-Internet devices, with minimal development facilities, to “quickly” create interesting high-tech applications for the new ranges of Internet products that are envisaged by the pervasive computing vision.

KEYWORDS

Embedded-Internet, wireless-Internet, Internet-appliances, pervasive computing, ubiquitous computing

1. INTRODUCTION

The development of the Internet is breathtaking having, in terms of the general public’s use, grown from virtually zero to over 200 million users in a little over 10 years [Facts 03]. Perhaps even more remarkable is mobile phone technology which, in a similar period, has grown from virtually zero to a truly massive 680 million mobile phone users [GSM 01]. However dwarfing all these is a somewhat quieter but just as significant revolution, the spread of small cheap processors into everyday products, so-called embedded computers. Recent figures suggest that 8 billion microprocessors are produced annually, but that only 2% of them go into PCs, most ending up as embedded-computers [Metcalfe 01]. Embedded computers are processors that are integrated into appliances and machines. They generally don’t look like computers, not having keyboards or displays and running dedicated programs. They find themselves in such places as video recorders, washing machines, lift controllers, mobile phones and all manner of everyday electronic appliances. Their application is now so widespread that it has become common to refer to this increasingly dominant computing paradigm as pervasive or ubiquitous computing. In fact the vision for pervasive computing does not stop at current household appliances but targets the using of nano-technology to embed computers into hitherto unconventional locations such as clothing fibres, paint pigments and dust [Hollar 00]. An essential aspect of these new embedded computers is a means to communicate with them, and they with each other, thus most current thinking and work on embedded computers sees them as having network connections [Callaghan et al 02]. Therefore the combination of appliances, embedded computer and Internet based networking beckons a new, massive and lucrative market that is drawing in the worlds major companies such as, Philips, Hewlett-Packard and Microsoft (to name but a few) [Bruno 02]. These organizations are investing heavily into related research in the belief it will one-day Internet-appliances and pervasive computing will become a major market.

The work described in this paper addresses part of this vision by investigating the use of WAP mobile phones, wireless PDAs and Desktop PCs to interface with embedded Internet appliances allowing people to remotely connect to, configure and control their appliances via the Internet.

2. Exemplary Vision Scenario

Tessa, a busy airhostess working for Singapore Airlines, is very much inspired by the Internet technology. She lives on her own in a rented flat in London where she is based. Tessa enjoys her job and loves plants. Her hobby (some of her friends say, obsession!) is keeping plants that are rare and difficult to maintain.

Being alone, and travelling frequently would normally present difficulties for Tessa as there would be nobody at home to look after her plants and flowers while she is away. In addition, as she is living far away from her friends and family, she lacks friends or people who share her interests. As anyone could imagine, Tessa feels heartbroken to see her beloved plants and flowers grew unhealthily (and some even die) when her job takes her away.

As Tessa is living in the "Internet Age" and inspired by the technology, she came across a circle of like-minded people when she was surfing the World Wide Web one day. She found an e-commerce company selling stylish Internet-based systems for caring plants. The advertisements stated that from any web access point, or her mobile phone, she could "see" and care for her beloved plants while she was away travelling. Moreover, the company provided a web based discussion group "the plant circle" which seemed to operate like a group of friends exchanging ideas on how they keep their rare plants. Tessa was thrilled and in no time, she made friends with similar minded people and bought herself an Embedded-Internet plant care system. Having bought the system, TESA also found that the "the plant circle" allowed her to see other people's plants, comparing notes with them and establishing many lasting friendships as well.

Some time later, Tessa was on another trip abroad. As she stepped out of a taxi in Singapore airport and watered her beloved plants back in London from her mobile phone, she wondered to herself "what must life have been like in the dark ages, before the embedded-Internet?

3. Related Work.

Numerous organizations are engaged in research in this area. For example the EUs Disappearing Computer research program has funded some 16 consortiums to investigate aspects of the vision for what are essentially networked embedded computers [ISTAG 01, Holmes et al 02, Cornish and Holmes 02, Callaghan et al 01]. Some current examples of products include an Internet alarm clock that checks the conditions of the road traffic over the Internet in the early hours of the morning using this information to modify the time of the "wake up" alarm signal [Moyer et al 00]. Another Internet appliance, the Internet toaster, that originated from work at Brunel University, accesses the weather forecast using an Internet link to local Met Office information, and then burns it onto a piece of bread [Southgate 01]. The iPot, an Internet pot (kettle), is an appliance that in addition to boiling water, sends usage statistics to a website that can be used by to track a users' tea-drinking patterns [Zojirushi 01]. The target market for the iPot is elderly people whose family live too far away for them to directly care for them, and who thus could use the iPot to check if they are ok by using the Internet to observe their tea-drinking routine pattern. The Korean manufacturer, LG, produces a more up-market and comprehensive range of domestic Internet appliances. For example, they have transformed a normal domestic fridge into an Internet fridge [LG]. This is essentially a refrigerator with an inbuilt multimedia PC that in addition to the usual web surfing (eg for recipes, food shopping etc), teleconferencing (eg family, friends, customer support etc) provides specialist functions such electronic notes and configuration management of other home network appliances. Of course, communication is a critical part of this vision and most mobile phone companies are operating projects in this area. For instance, the "Orange-at-Home" is investigating using mobile phones to control the devices at home [Orange]. This work is closely related to research into location based services which seeks to use mobile phones as a context aware interface to services, including Internet appliances, in the user locality [Callaghan et al 02]. There are a number of companies producing embedded Internet devices. Table 1 shows some of the key players and systems parameters. All have a rich set of I/O options including Ethernet, one-wire and IrDA support. All support Java although their performance varies, generally in proportion to the cost. In this work we have used one of the lowest performance devices, the Dallas TINI system, but it has the virtue that it is also the cheapest and if an application can run satisfactorily in this system, it will certainly run on any of the alternative systems.

	TINI390 1MB	TINI400	JStik	SaJe
JVM edition, type, size	custom 1.1.8 version firmware, 448 KBytes	custom 1.1.8 version firmware, 448 KBytes	J2ME/CLDC native, 0 KBytes (in silicon)	J2ME/CLDC native, 0 KBytes (in silicon)
Java Tools	Standard JDK	Standard JDK	Standard JDK	Standard JDK
RealTime Java Support?	no	no	yes	yes
JINI support	yes	yes	yes	yes
thread switch	2 msec	2 msec	1 usec	<1 usec
byte codes per sec	??	??	15,000,000	15,000,000
No. of threads	16 max	16 max	unlimited	unlimited
SRAM	512 KB / 1 MB	512 KB / 1 MB	1-2MB	1 MB
Flash	512K note1, note4	2 MBytes	4-8MB	4 MB
Size (inches)	4.25 x 1.25 SIMM72	4.25 x 1.25 SIMM72	3.00 x 2.65 SIMM30	3.9 x 6.2 Euroboard
Est cost	$85	under $100	$299	$399
URL	ibutton.com/tini	www.tstik.com	jstik.com	saje.systronix.com

Table 1 - Some off-the-shelf embedded-internet devices[1]

4. TESA - An Embedded-Internet Application

In order to illustrate and evaluate the embedded Internet design process, we chose to target a novel Internet-appliance, a botanical care system, called TESA (Towards Embedded-Internet System Applications) [Chin 03]. This appliance, see figure 1, took the form of a small self-contained enclosure to contain houseplant with its own artificial environment (ie light, heat etc).

Figure 1 - The TESA Appliance

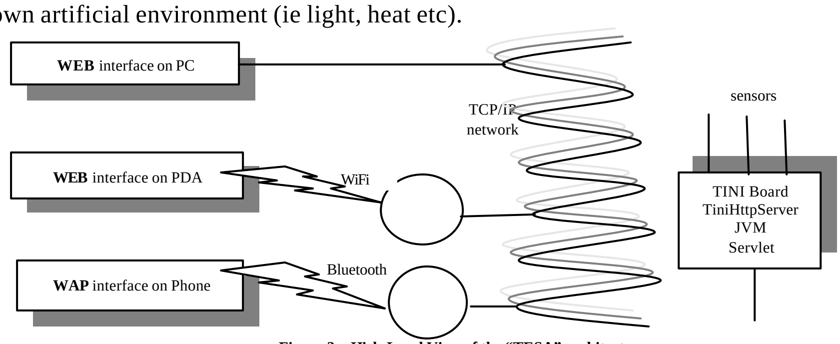

Figure 2 – High-Level View of the "TESA" architecture

1 abridged version of http://jstik.systronix.com/compare.htm

The TESA computing architecture comprised of a TINI embedded Internet device which was capable of interacting with Desktop PCs, WAP mobile phones, and wireless PDAs as illustrated in figure 2.

5. Implementation

With reference to the physical view of the system in Figure 1, the enclosure contained lights (top and bottom), a heater, a fan, a temperature sensor and a moisture sensor. The main computing was based around a TINI Dallas Semiconductor embedded-Internet device which supported HTTP, FTP Internet protocols and Telnet sessions.

The system software, shown in figure 3, was written in Java, from the back-end system classes to the front-end server implementations. Java provided high-level abstractions and platform independence, thus making the system robust and portable.

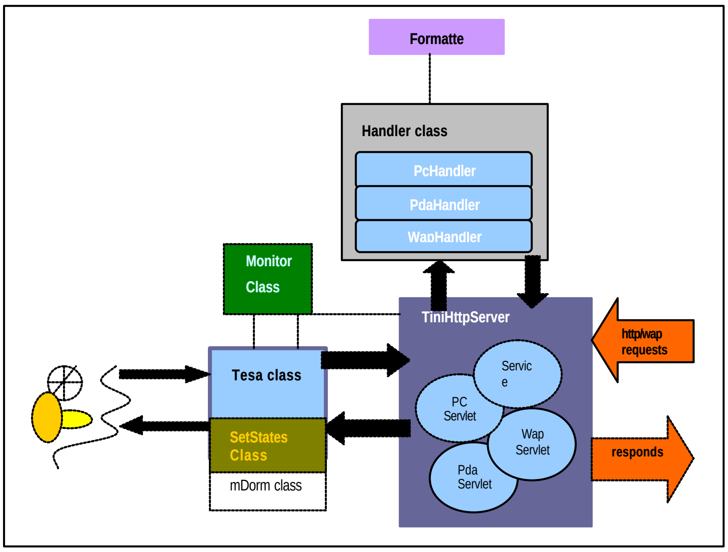

Figure 3. The TESA Software Architecture.

Three interfaces were developed, a conventional desktop PC, a handheld PDA and a WAP phone. Apart from the WAP interface was written in WML, the other two were written in standard Web markup language the HTML. Figures 4, 5 and 6 show the three interfaces.

A backend server engine was used on TESA to act as the server for responding to any of these three client requests. Because the computational handling of the different types of client, with differing communication, display and OSs was very different, the application needed to distinguish the type of the client connection so as to respond appropriately.

To be able to identify the medium of the connection and act upon receiving the request, the system employed a "receptionist" strategy whereby for each different means of connection, its request was dealt with by the main Servlet component which would (1) identify who the client was, (2), pass it to the appropriate department for handling the request. The main Servlet has no interest of what the client's request might be. The system WAP interface communication architecture was centred around a WAP Servlet whilst the PC and PDA were handled by a common Servlet component. The system class however, was accessed and "seen" by all other Servlets components. Its job is primarily interaction with the system hardware devices (such as changing the hardware device status and retrieving the system current status). A separate monitor class was implemented to run to control the system environmental temperature continuously in the background.

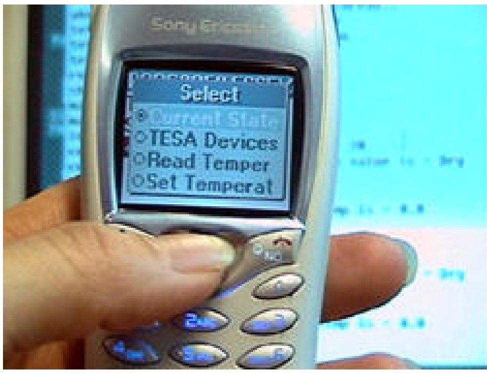

Figure 4. The WAP interface

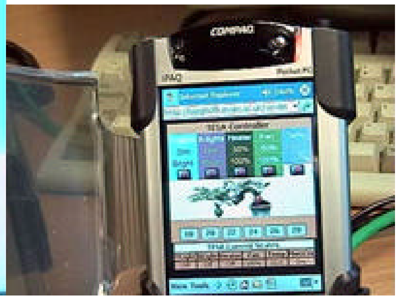

Figure 5. The PDA interface

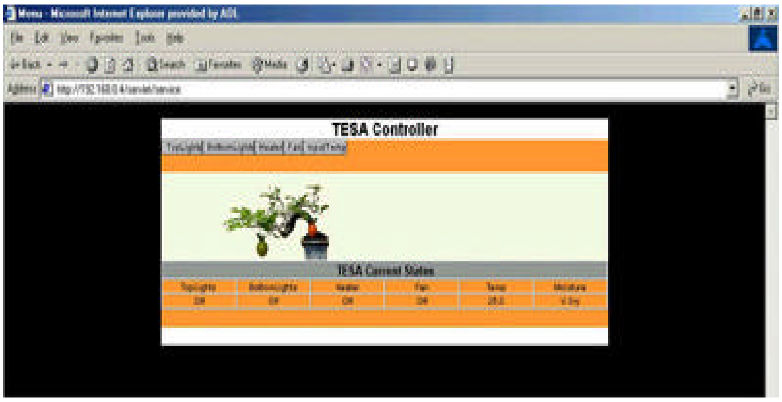

Figure 6. The PC WEB interface.

6. Experimental Setup & Evaluation

The experimental setup consisted of a PC, laptop, PDA and WAP mobile phone using a combination of wired-IP, Bluetooth, WiFi (802.11b) and WAP based GPRS gateway services. TESA was used as the system server. The experiment was set to evaluate the general performance of the system by examining architectural issues such as:

? Whether the system was capable of identifying the communication medium and performing the requested task correctly - this was to assess whether the architecture could correctly deal with multi-modal interface requests.

? Whether the system was able to maintain its consistency whilst simultaneously handing external requests and controlling the local environment - this was to assess whether a relatively low-performance embedded-Internet processor could manage such a typical application load.

? Whether the system behaved what it was supposed to behave when 3 different communication mediums sent the same request simultaneously - this was to assess whether the event handling architecture was suitable.

Figure 7 shows the experiment environment.

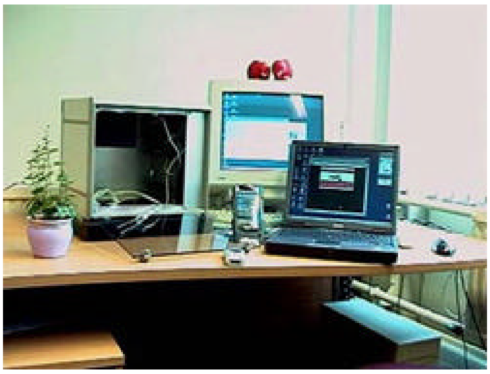

Figure 7. TESA experiment environment.

The system performed well, both satisfying the above tests and providing evidence that such low cost embedded-Internet devices are suitable for the building new generations of Internet appliances.

The main findings were that TINI (the lowest performance embedded Internet device of those considered) was more than adequate for the application. Monitoring the date flow it became obvious that this could be characterised by generation of sparse events and service requests. Should the application require intense event handling, or media streaming, then it is likely a higher performance device would be been necessary. In this case the generic architecture has been designed so that it could accommodate such a change by simply exchanging embedded processor boards. As expected, the much lower bandwidth of the GSM connection made it noticeably slower than the other communication modes. The development process itself, which revolved around Java SDK, was remarkably simple and effective. Given the low cost of the device (approx $50), despite the computational limitations noted above, it was felt that the system could be used to develop numerous new internet appliance applications, of which the "plant care" system is just one example. In this respect the project was felt to be successful and a useful signpost of what is possible from such minimal Internet systems.

7. Concluding Remarks

The work succeeded in its aims of demonstrating that the newly emerging generations of cheap embedded-Internet devices can be used to make Internet-appliances. The processor we employed, TINI, is based on a low performance 33MHz processor with 0.5 to 1MB of memory, costing less that $50. Clearly such devices have limitations and need to be selected by carefully considering the application needs. In this case the application demanded only intermittent data and the TINI would not be suitable for intensive data streaming. However, it is contended that there are numerous applications, such as the plant care appliance, described in this paper where they are eminently suitable. We showed that the differing handling mechanisms required to deal with the variety of client technologies ranging from small screen WAP based phones, through Bluetooth enabled PDAs through to wired-IP or WiFi PCs which large screens were easily handled by these small embedded Internet devices. Thus this work has demonstrated that these new generations of embedded-Internet devices not only open up novel types of Internet applications, but that the low cost and minimal development environment provide a quick and low-overhead way for developers to enter this new and exciting pervasive Internet appliance market. Note to Reviewers: We could demonstrate this system as part of any presentation.

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