From development in the laboratory to deployment in the home. Trouble and strife with sensor networks.

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***Abstract*—This paper examines the process of customizing Particle sensors for use in a home energy monitoring project. Our developments affected sensor hardware, sensor software and data capture. The developed sensors have been deployed in two homes in the UK. We examine the issues in using 3rd party toolkits to undertake research and suggest design and process enhancements to better assist with the deployment of sensors in homes.**

***Index Terms*—sensor nodes, ubiquitous computing, home applications, energy.**

I. Introduction

The domestic environment has long been seen as an opportunity space for the deployment of ubiquitous computing devices, with much research being focussed on understanding the workings of modern households. Findings of such studies are used to better inform deployments of ubicomp devices into purpose built homes of the future [1] [2]. These buildings bear little resemblance to the actual homes of the core housing stock which have typically evolved in size and infrastructure over the years [3]. It is these mutated buildings that will need to be designed for if ubicomp applications in the home are to have a more mainstream uptake.

As part of a study into ubiquitous computing in domestic environments we wished to monitor the total energy usage in the home. We did this by deploying our own sensors onto wireless tranciever boards called "Particles", a wireless sensor node toolkit, developed by Teco [4]. Our sensors monitor power consumption from the electricity mains into the house and the water temperature differentials about the boiler. The temperature differentials were chosen as an easier option than measuring the actual gas mains input to the property using ultrasonics. These sensor readings were wirelessly broadcast to a computer which acted as a data logger and relayed the readings through the home wireless (802.11) network to our lab.

In this paper we discuss the design, development and installation issues surrounding the use of sensors and "Particles". Rather than discussing application opportunities for these wireless sensor nodes, a topic which has been extensively covered by other research [5] [6] [7] [8], we discuss the difficulties encountered in building and deploying such devices for real home environments, and make suggestions to better inform their design. This is important because if we are to move ubicomp research from prototype in-lab deployments to everyday deployments in authentic settings, then we need to understand the lessons learnt from such experiences and develop more repeatable and robust processes and technologies to enable this deployment. The data collected is currently being analysed and will be the subject of another paper.

II. What we wanted to do and why

Results of previous studies on experiences of use of domestic technology had revealed concern with energy use to be one emerging theme [5]. In order to allow inhabitants to better understand energy consumption within the home, we wanted to monitor the usage of the two main energy resources feeding the home; that of gas and electricity. Using the real time data from these sensors we wished to investigate possible carbon usage representations which were to be displayed and presented to the household.

Since we were interested in the effect that these representations might have it was necessary to undertake a base line study in which we monitored the household's existing energy usage. To do this we needed to develop two sensors that could be interfaced onto two separate "Particles", one a current clamp sensor and the other a series of

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multiplexed temperature sensors. It was important that this deployment of sensors be as transparent as possible to the occupants of the house so as to limit any resulting change in behaviour that might occur through being aware of the energy services being monitored.

We have chosen Particles as our platform as they provide both hardware and software middleware on top of which sensor network applications can be developed. We wanted to deploy our own custom-built sensors running our own custom-built algorithms using off the shelf infrastructure provided by Particles. This is because using off the shelf infrastructure saves developing hardware and low-level software which allows us to focus on our real research questions. Particles provided an affordable platform, which had a good match to our technical needs.

Based on critical reflection and previous experiences with home studies, we adopted the following as desirable properties of sensor networks to be installed in homes for research studying deployment experiences over time. These include:

Easy reconfigurability: It should be possible to deploy custom-built sensors running custom-built algorithms. Moreover, a sensor network should actively support the addition of new nodes and sensors and facilitate mobility to easily relocate sensors should the need arise.

Non-invasive installation: sensor deployment should not involve cutting of wires/pipes.

Low maintenance: The need for frequent battery replacement should be minimised. In particular in this case, as the project is investigating "green" issues, overly frequent battery replacement would be a poor reflection. The sensor hardware must be robust and be able to withstand transportation and being set up.

Low-impact on the occupants of the home: The installation needs to be unobtrusive, transparently safe, and protected from children and pets.

Installation needs to be easily and quickly configured to the layout of the home as there is limited scope for site-visits and lengthy in-home procedures in the lives of busy participants. As well as technical interest our project is studying the opinions-of-, reactions-by- and impact-on- the occupants of the home of feedback on the sensed data. So site visits must involve the participants and combine more human aspects of the research rather than take on the character of a complex technical installation. Flexibility is needed to schedule visits at times that suit the occupants of the home and sensitivity is needed once in the home to that the researchers are guests. Once installed further site visits may be required, to discuss findings, correct problems found and advance the research. However, these typically need to be arranged in advance and it is important not to erode the goodwill of participants (or affect their behaviour) by becoming a constant presence in their homes.

III. Experimental Design in the Lab

We shall summarise the hardware and software we started with and then describe our work to address the necessary reconfigurations for our research; and approach to installation and maintenance in the home. This work took place in three phases: setting up the development environment and conducting preliminary testing in the lab; conducting further testing by installing the prototype into a researcher's home; and finally moving the installation into a participant's home to monitor their energy usage patterns. We discuss each in turn.

A. Development Environment

1) Particles:

The Particle computer system that we have used is the 2/32 version of the pParticle. This includes a built-in microcontroller, flash memory, a real time clock, power supply circuits, radio transmitter, LEDs, buzzer and an onboard connector providing access to the I2C and serial communication lines, digital I/O pins and pins providing access to the on-board 10-bit Analog-to-Digital converter [9]. The Particle provides a connector for a sensor board. We have used the sSimp, bespoke temperature sensor, and breakout boards. The Particle is powered by a single 1.5V battery.

The Particles come preloaded with its own software called the 'Particle-Base system'. The code we used was the one available for 2/32 version of Particles which can also be downloaded from the Particle's website. It is written in C and source code is supplied in order to integrate new code to be programmed into the PIC. It includes files supporting the boards, sensors and system level tasks including OS functionality and running the protocol stack. In order to upload our own programs, we used the GALEP-4 universal programmer along with the GALEP32 software uploaded on our computer.

The compiler we have used is the CCS compiler version 3.222. We had to be careful about the compiler version we used since there were problems in compiling the Particle software for the 2/32 Particle with the earlier versions. Some of the functions written for 2/32 were not being recognised by the older versions of the compiler. Moreover, even with this compiler, we were sometimes getting error messages with the compiler halting the build. These were documented errors with the CCS compiler [10] which could be ignored as the .hex files were still being generated.

We have used a 1.5 GHz Celeron M Laptop with 1 MB L2 cache, 512MB DDR2 running a Microsoft Windows XP SP2 Home edition. Three pieces of software ran on the laptop in relation to the gathering of sensor data.

1. A Particle bridge which allows data to be read from the Particle hardware attached to the laptop.

2. A Particle logger which read data from the Particle bridge and writes to a log file

3. A log copier which copies logs from the laptop to an ftp site every hour.

These three software elements needed consistency in their labelling between the data collected from the transducers through to that reported to the data logger. There was also a need to ensure strict version control to these software components.

B. Reconfiguration for New Sensors

We have used the flexibility afforded by the Particles to develop the necessary new hardware and software drivers for the types of sensors we wanted to deploy.

On choosing the “Particle” as our sensor node board, we wished to exploit the sensor’s sSimp piggy back board which had spare connection points made available for the use of a force sensor of the variable resistor type. This was seen as a quick and simple way in which to add a purpose built sensor which could report electrical current usage of a mains current supply. This sensor used a clamp which detected induced current which after some signal conditioning provided a 0 to 3.3 voltage swing as an analogue input to the “Particle”. This approach was taken so that we could deploy the clamp straight away in to our lab’s small kitchen area as a preliminary test and monitor electricity usage. We saw this as a way of identifying “problem” areas with our equipment and scenario as quickly as possible and therefore inform our study and system design.

Whilst running the system in the lab to test the monitoring of electricity use, we wanted to prepare the conan connector board supplied by Teco, to interface our two bespoke sensors: the electricity sensor and the multiplexed temperature sensor. Both of these sensors were non invasive types, and did not require any interruption of services, which avoided any chance of high-voltage exposure or leaking pipes.

1) Current Sensor

We bought a commercial clamp-on current sensor which uses inductance to generate a reading. We used two versions: one designed for a single socket and another for the mains feed into the house. These gave full-scale deflections of 10A and 50A respectively, and in each case had a resolution of 256 steps due to the processing within the sensor.

We used a redundant input on the plug-in sSimp sensor board to connect our electricity and have made the necessary changes in the driver software provided for the force sensor. The driver code was changed to include a 10-bit ADC sensor as our default ADC. It also entailed rescaling the values being read to sweep between 0V to 3.3V since Particles work at 3.3V.

2) Temperature Sensors

We developed a board to attach to the plug-in breakout sensor board (which simply exposes the connector pins for soldering). This new board multiplexes six voltage-divider sensor circuits and allows the driving of these sensors to be switched on and off. We used this to connect six thermistors, which could then be read in turn to give various temperature readings. Separate thermistors allowed a more straightforward installation as they could be taped to pipes more easily than PCB mounted devices. Again, this required some modifications to the driver code to extract the data: for instance each sensor required 5ms delay between activation and ADC reading, due to the circuit used. While the radio protocol of the Particle forces maximum computing slots (without extra work to recover from interrupts), these delays could be managed.

C. Hacking the electronics and software:

Although we are told within the on-line documentation that the sSimp board has the option of adding a force sensor to the board, we had difficulty in identifying where on the board we were to wire such a sensor. The documentation for the sSimp board did not include a circuit diagram nor could we find any help via the on-line forums mediated by Teco. There were a number of possible places where the designer’s might have placed available pins and we used our multimeter to try and electronically decipher which of the holes in the board were the ones to use for activating the force sensor input. This approach did not prove conclusive so we placed a post on the on the forum site and asked for help. After a few days we received a response from one of the mediators who guided us to some solder points on the board that we didn’t even consider investigating. With this information we were able to proceed with interfacing our sensor on to the forces sensor input with little further difficulty.

D. Data Reporting and the Radio Protocol

Since a substantial percentage of battery power is expended in radio communication, our power saving algorithms have focussed on reducing the rate of transmission of data. However, we chose not to radically rework the existing Particle network protocol. This protocol is called AwareCon [11]. This is an ad-hoc self organised synchronised protocol using Time Division Multiple Access (TDMA). The ad-hoc link establishment takes 12ms. Each time slot in the TDMA structure is 13ms long. Each packet consists of 64Bytes of payload. A data rate of 48kBits/s at a frequency of 868 MHz is promised [11].

We found that both types of sensors had a certain amount of noise. This was about 1% of the full scale deflection. However, significant changes (domestic appliances or taps being operated) generate readings which are significant beyond this. Homes naturally have periods of inactivity (e.g. during the day when people are at work/school and at night when they are asleep), periods of occupancy but only occasional activity with respect to our sensors (e.g. toilet visits while watching TV) and periods of greater input volume to our sensors (e.g. meal times). The goal of the research is to provide a real-time representation of energy use, so the long-term aggregation and scheduling of communications that a scientific monitoring experiment might apply cannot be used here.

The driver code for the sSimp board allows the data rate to be varied, up to a maximum interval. Clearly a single, low, data rate would miss interesting activity while frequent transmission will drain the battery far too quickly. However as the rate can be varied if we can remove the noise from the data then during periods of inactivity we can use a long interval (which happily provides some redundancy and feedback that the system is working), and when significant change is detected the frequency can be increased. This approach could be refined further (we do not modulate load on the CPU) and benefits from being a very simple network where each sensor node reports to a mains-powered laptop.

The following algorithm was worked into the existing Particle code: We maintain an average of the last 10 readings. The current reading is compared to this. If it is different by more than a set threshold then the rate at which data is sent is set to once every 6.66 seconds; otherwise the data rate is set to 7.1 minutes. These time values came from the way the Particle code was organised to set the times for the rate of data sending. To increase the time intervals between sending of data to more than 7.1 minutes would have meant a substantial reworking of the code. This would have defeated our aim of rapid deployment of our application. The Particle sleeps for 3 seconds between taking readings.

The electricity sensor sends data once every 6.66 seconds if the reading is 5% above or below the average. This value was reached by carrying out observations starting with setting up the sensor to send data at the higher rate if the reading was 10% above or below the average. However, the value of 10% resulted in the sensors missing events such as turning on of an electric kettle in the lab. Subsequently, the 5% value was selected and major events began to be detected.

The water sensor had trigger levels of 5% over and 1% under. This 1% value was chosen due to the thermal inertia in the sensor and the slow heat dissipation in the pipes our sensors were attached to. Due to the slow heat dissipation, the difference between the first and the tenth reading was less than 5%. Selecting the 1% value meant that we could more accurately discern events like a hot water tap being turned off. We were more interested in on/off events than actual temperature and we found that detectable cooling started within 60s, which was sufficient for this project.

The code we hacked was the driver code for the sSimp board's set of 6 sensors. This code already provided for the synchronisation of sending of data with the time slots of the Awarecon protocol. We needed to change the code so as to be able to drive our set of 6 temperature sensors. This was done for each sensor by having the 10 bit ADC read the voltage values inputted from the temperature sensor and then converting them to swing between 0V and 3.3V. We changed the pin definitions as well as added code to drive the multiplexer of our custom built sensor board. We also had to weave in our power saving algorithm into the driver code. This meant carefully walking through the code to decide where to add our code and yet not break the existing functionalities

These changes gave us an improvement in battery life from 10-12 hours to over 5 days. We also changed the batteries from the AA size to D size further boosting the battery life to around 3 weeks. This avoided unnecessary visits just for battery replacement. We can look to ways of increasing the interval between sending data though that might entail a substantial reworking of the code if we want to keep the protocol intact.

IV. Installation and Experience in the Home

Rather than going straight into our participant's house with our technology we thought it prudent to first install our equipment into the home of one of our researchers. This was seen as an opportunity to identify site specific problems which may exist that were not apparent in the lab.

A. *Researchers home*

Once we had completed our pre–installation visit, where we planned our equipment placement and considered the health and safety implications. We installed and ran; the plug sensor (10amp), the temperature sensor, and a wireless data logger computer, for a two week period over Christmas.

A number of site specific issues became apparent during this period, many of which have potential design implications for both the system and the devices used within. These are as follows:

1) *Positioning of sensor nodes*

We were interested in monitoring the electricity usage about a power extension block that was connected to a mains wall outlet socket from the wall in the living room. At the same time as this we wanted to place the temperature sensors on to the pipes about the boiler which was kept in a cupboard in the kitchen. We needed to position the computer doing the data logging within wireless range of the two sensors.

After considering other operational issues about the placement of the computer, we decided the ideal site would be somewhere out of the way in the kitchen. This did not cause us any difficulty and, after checking that the communication was steady and repeatable, we settled on a position. However we did need to consider the dynamics of the home and how things changed during the day. Were there likely to be clusters of people the kitchen in the evening? Was stuff going to be brought in to the house that might interfere with the radio signal? Will other electrical devices not currently active about the house have an effect?

The two sensors needed to be placed in quite different environments each with its challenge for mounting; one a dusty, hot boiler cabinet, the other a confined cluttered back-space within a television cabinet. Ensuring the position and orientation of the sensors was achieved with using gaffer tape. Protection from dust, water or being knocked, was provided by housing the boards in a splash proof box. Even with this arrangement, the wires that ran from the transducers to the signal processor and wireless transmitter, proved a potential snag risk which the people in the house needed to be aware of.

2) *People*

Whilst placing the technology in our researcher's home it became apparent that we needed to be sensitive to all of the occupants of the house. We found concern from some members of the household to having "sensors" in their home.

What would such data reveal about them? Do they want such information to be highlighted? Also unexpected issues were identified as problematic, such as the LED light on the board and the fan noise from the laptop computer were found to be annoying. Although these concerns are social in their nature, we found it imperative to be sensitive to them. Without the agreement of all members of the household it is unlikely the study will be accepted or, if it is the interpretation of the data accurate.

In summary though, both trial installations – in the lab and in a home – were found to be critical for helping ensure that many problems were identified and fixed before the deployment in a 'real' participant's home.

B. Participants home

Our participants, Peter and Jane (Pseudonyms used), were a middle aged couple with one 14 year old son living in a Victorian terraced house in the South of England.

As with our researcher's home, we undertook a pre-installation site visit where we discussed what we wished to do as well as possible sites for placement of the equipment. The position of our sensors and the computer hosting the data logger can be seen in Fig 1.

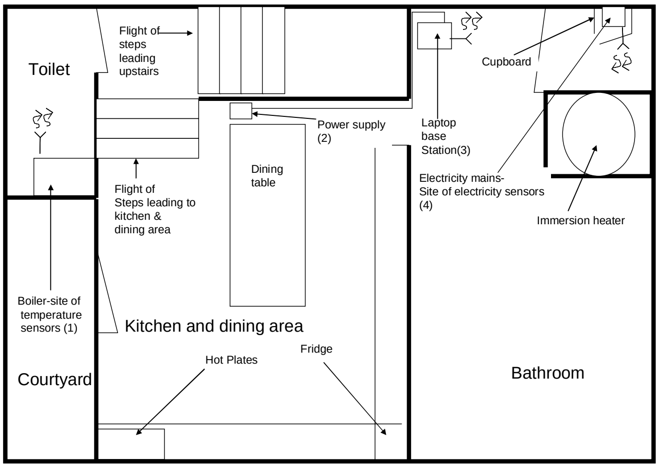

Fig. 1. Plan of the Kitchen and bathroom areas showing placement of our technology

1) Positioning of sensor nodes

What became quickly apparent were the differences between our researcher's, and our participant's, houses. The participant's house was spread over three floors and had a smaller cross-section which lead to many of the utilities being squeezed in. Another feature was of this house was its age, it had evolved over the years with rooms changing form and function with the various owners. An example of the effect of this can be seen with the boiler being mounted in the toilet space, and the service pipes squashed between the top of the boiler and the ceiling, as shown in Fig 2 (left).

a) Temperature sensor

After our site visit we rethought our initial choice for the temperature sensor placement, which was in the immersion heating cabinet and considered alternative options. We had two candidates (Fig 2), either on the pipes contained in the immersion heater cabinet in the bathroom, or about the boiler in the toilet. After deciphering the pipes for the immersion heater and comparing their function with those available at the boiler, we chose the boiler. The boiler was used for the hot water and central heating in the house and fed the immersion heater which had an electric element to supplement further heating.

This choice meant that the thermistors had to be placed within a narrow space on to the pipes at the top of the boiler. These thermistors had a limited length of cable available to the Particle radio transceiver which had to be placed close to the boiler. The top of the boiler was initially considered but seen to be too hot when running, so we mounted the transceiver box to the wall with gaffer tape. This was not seen as an ideal solution but to extend the wires on-site was not possible in the time available. Clearly we would have benefited by having another site visit to identify the required transducer wire lengths before installing the equipment.

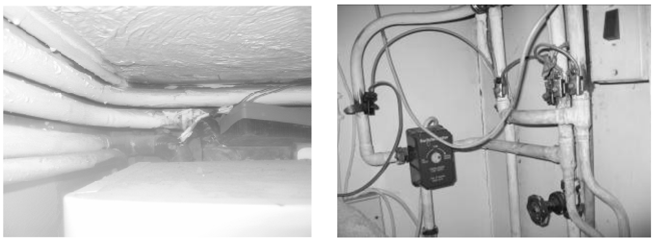

Fig. 2. Left. Service pipes about the boiler to which our sensors were attached, Right. Service pipes in the immersion heater cabinet.

b) Current sensor

For this study we had decided to monitor the mains input to the house and not a particular 13 amp plug, as we did in the researcher's house. This change was taken to get an overall impression of the household energy profile rather than a single distribution point. In our participants house there was a small cabinet which housed the electricity meter to which it was straight forward to clamp our sensor onto, see fig 3.

The positioning of the Particle transceiver was likewise non problematic since it could easily sit on the bottom of the cabinet without being disturbed.

Fig. 3 Left. Sensor in the corner of the mains cabinet, Right. The mains cabinet to the house by the ceiling of the corridor.

c) Data logging Computer

As with the researcher's house we needed to place the data logger in range of the two Particles whilst out of the way enough not to be knocked by people passing. Although we had changed the position of the temperature sensors we were fortunate to be able to use the original site identified which was by a boot rack in a narrow corridor.

Although the hardware was sited to minimise disruption, we did not consider that the software too needed protection from other services running in the background of the windows operating system. For example we found automatic updates via a wireless network to be the cause of the logging software to stop, but it took some time to recognise this as the problem and not a problem with source code.

At the time of writing, this installation in now running the participant's home and we are working with them to explore patterns of energy usage and issues around feedback of usage information. The findings of this study will be analysed and reported elsewhere. Our focus here is to go on and reflect on the experiences we have had in working with sensors and Particle boards and trying to deploy these in an 'everyday' home.

V. Design implications

In designing and deploying our sensors into an average home we came across many challenges. Here we reflect on the lessons learnt through having to resolve these problems. These insights have implications for both the sensor board designer as well as the systems integrator. We present these as working with toolkits, lessons about the design process and methodologies for deployment.

A. Working with toolkits

The use of both hardware and software toolkits offer much promise in supporting rapid prototyping of distributed sensor arrangements. The ability to quickly rearrange sensor deployments in space and in scope facilitates user centered prototyping of ubicomp sensor arrangements in-situ.

An example of this can be seen by Peter and Jane on seeing sensor data collected from an earlier time, asked for more information about the electricity use within a particular time of day when they believed the washing machine to be on. Our response is to place another wireless sensor node in-line with the washing machine's electric plug, and use this added granularity to further inform our representation design. To achieve this modification to our system we will need to:

1. Add an additional current sensor to another sensor node board.
2. Package the new sensor into a household plug and interface to the Particle.
3. Load existing code to new board
4. Test the new plug sensor arrangement in the research lab.
5. Conduct pre-installation visit with prototype sensor board, checking for health and safety issues, as well as performance monitoring.
6. Register full scale deflection for the new sensor and calibrate
7. Adjust receiving code
8. Adjust logger code to include new sensor
9. Rewrite display software with appropriate scaling to reflect changes.

The need to make these incremental changes to deployed devices with a minimum of disruption is central to prototyping in the home. This intrinsic need has implications for toolkit design:

1) Hardware

Interface connection points should be physically and electronically robust, allowing for disconnection and reconnection of input sensors. Easily configurable indicator LED's that can reflect system behaviour becomes a useful fault finding tool by saving dismantling and re-fixing of the installation, which can often be the cause of further breakdowns.

2) Software

Many applications of pervasive computing lie in the domain of non-IT researchers. Commonly understood lessons in IT might not be known to non-IT researchers leading to erroneous design decisions. In the case of our temperature sensor we needed to edit 259 lines and add 254 lines of code for the driver code for sSimp, across a total of 11 files.

Therefore, sufficient attention might be paid to design user friendly interfaces with easy to use 'hooks' into the software/hardware capabilities of the tool-kit. These hooks might be designed so as to ensure that the underlying integrity of the tool-kit is maintained but at the same time appropriate flexibility is afforded to the application developers. The technical details of such hooks would have to be transparent to the user who can instead focus on applying the hook's capabilities to their specific problem domains.

3) Packaging

The environments that these wireless sensor nodes may be placed in can vary hugely. They can often be sited in moist, hot, dusty or dirty places, or close to electronically noisy equipment like washing machines or kitchen equipment like coffee grinders or food mixers. Busy people thoroughfares might be the place of interest or as in one of our cases, the narrow space between boiler and ceiling. In our two deployments we came across hot, dry, dusty, moist, electrically noisy, people busy and potentially gaseous environments.

The packaging for these sensor nodes, and any receiver technology, needs to provide a fixing method, for example; screw holes, clamp or magnet. It should also provide protection, both physical and electronic, from the environment whilst at the same time offer easily viewed indicator lights to assist in situ maintenance and fault finding.

4) Support

In using toolkits to further our designs it became essential to have points of reference to which we could turn to. We found the lack of circuit diagram for the sensor board meant a delay of approximately 10 days to our deployment schedule. The access to, and navigation of, these stores of information became crucial and will quite often be the difference between success and failure. The cost of support can be substantial with many man hours spent in writing manuals for different users who have different levels of engagement with the equipment. The creation of well written support documentation is often under valued and the user testing process to inform such documentation ignored. However there are some elements of support documentation that can be key in getting to grips with development platforms. These are discussed below;

a) Documentation

Documentation very much becomes the backbone behind understanding the scope of the toolkit and consequently the quality of information should be accurate, easily understood and organised in a logical fashion. This documentation should also be aligned to version control of hardware and software platforms.

The use of schematics for over viewing the toolkit's software and hardware processes can be particularly useful, as are circuit diagrams of interface boards. If such diagrams are coupled with application examples of typical configurations, a very useful landscape from which to further develop from is provided.

b) Forums

Online forums supported by the toolkit provider are another potentially rich source of information dissemination, where experiences from other toolkit users can be mined and lessons learnt shared. These sites are often arranged by hardware or software categories and it can be difficult to find support for a particular issue that will more often than not have references across a number of such categories. A good search engine can be very helpful here.

B. The design process

When using real working homes as an application domain it is essential to prototype device design in situ so that the symbiotic relationship between place, user and device can be better understood. This is by no means a misunderstood design concept, prototyping beta release equipment "on site " is quite normal practice, and taught the world over as an integral part of the design process. So what is so different about carrying out our research within the domestic environment?

Installation in a real home brings to light many issues surrounding the reliability of underlying infrastructure which are hard to anticipate. Maintaining installations in another person's house is an expensive and time-consuming business. The response to an installation by the inhabitants that have to live with it may be emotional or illogical. In the home in which we installed energy sensors, Peter claimed to have noticed that he heard his freezer starting up more often since we had installed the sensors.

Designs can significantly benefit from crunching the whole design cycle into a shorter, faster, overlapping spiral [appliance design] which brings the user closer to the designer and builder. The traditional design process of prototyping in the laboratory moving through to testing in the field has increasingly been challenged. This being replaced with the user being involved in the initial design discussions and laboratory prototyping, whilst bringing the field testing of designs forward to include further prototyping informed by both user and site.

Contrary to this approach, the research community involved with deploying pervasive technologies into domestic environments have invested significantly into purposed built homes of the future [12] [13] [14], using these as test beds for ubicomp device study. Whereas these "homes of the future" undoubtedly have much to offer researchers, they come short in reflecting a true image of real homes with everyday occupancy. If we acknowledge the value of place in both "user centered design" and "device fit", what are the issues that need to be considered when putting ubicomp prototypes into real home environments?

C. Methodology for deploying sensor networks in everyday homes

In being invited into someone's home there is a need to treat the relationship between researcher(s) and home occupant(s) with the greatest of respect. This starting point of acknowledging the privileged position the researcher is in, should drive a professional approach that ensures the safe and sensitive deployment of any technology. Such an approach should include the following;

1. Risk assessment and hazard identification for technology undertaken for operation in the research laboratory, as well as for placement in the home.
2. Pre-testing of the equipment as closely as possible to the actual deployment circumstances prior to the installation.
3. Pre-installation site visit to foresee installation challenges and identify equipment needed. This could range from mounting brackets through to extensions for antennas, power or sensors.
4. A strategy for what happens to the installation when the power is cut from any mains driven equipment should be developed.

5. More flexible strategies for problem diagnosis since the researchers do not have contorl over the environment and more lateral thinking might be requried to understand problem sources
6. Consideration should be made of the insurance implications. What happens if your device burns the house down? In our case we were covered by university policies.
7. Sensitivity to possible privacy issues should not be overlooked. Often concerns are not talked about directly but might be played out through an unwillingness to have the technology placed in a particular place or on at a certain time of day. For example both Peter and Jane were sensitive to "outsiders" having hold of the captured data believing that they could be the target of company mail shots or even worse notafying criminals of occupancy patterns. Another concern might be being placed on data collection devices (audio or video), when they would wish not to.
8. Submission of study proposal to ethics committee.

All of the above suggestions minimise the inconvenience to the home owner and reassure them of a professional approach being taken. It is noted that the above methodological approach to undertaking ubicomp research in everyday environments has been based on a white middle class family in the United Kingdom, and to do such research outside this demographic, our approach would need to be sensitised to differing cultures.

VI. Conclusion

Rapid prototyping of sensor networks within domestic environments is not an easy process, with many considerations to be accounted for by the designers. The role of toolkits to facilitate the design process needs to be clearly understood. Wireless sensor nodes integrated into ubiquitous computing devices are an emerging technology, and consequently the supporting technologies are also in their infancy. Whilst it is a clear advantage to use such toolkits, it has been our experience that much work needs to be done in using these toolkits which are still the domain of the engineering specialist.

A well established principle in industry to facilitate the acceptance of new technologies into new or existing markets is to mediate between the end user and the development engineer, through employing application engineers. The application engineer understands the domain that such developments are to be situated in, and as such is able to apply their skills to better inform the equipment development, whilst at the same time fully exploit the development's existing technical scope.

Placing sensor driven ubiquitous technology into a real life domestic environment within a research context, demands the sensing platform to be robust, flexible and highly configurable, whilst at the same time the researcher needs to be able to understand both the environment and the technology. It is when these two elements come together that ubiquitous technology applications within the domestic environment have their best chance of working technically and socially.

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