COMMUNITY-BASED PUBLIC AUTHORING WITH MOBILE CHEMICAL SENSOR NETWORKS

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ABSTRACT

The Robotic Feral Public Authoring (RFPA) project seeks to combine low-cost robotics with geo-annotation in an innovative way for a novel approach to galvanising social activism on a local level around environmental issues. Adapting commercially available toy robots and remotely controlled vehicles with a variety of sensors and uploading the readings to a spatial annotation database for visualisation, we aim to explore new ways in which the exclusiveness of pollution sensing and robotics can be dispelled and a new sense of empowerment promoted. In this paper we introduce the current version of a mobile chemical sensor network node which forms the core of such an RFPA built around the Urban Tapestries platform. Finally, we report on our recent experiences during tests and community workshops at the London Fields park in East London.

INTRODUCTION

Our everyday lives are increasingly infused with electronic and digital technologies – facilitating new modes of communication as well as shifts in private behaviour in public spaces. These technologies also have an environmental impact; from increasing levels of background radiation to producing mountains of *disposable* artefacts, for which there are few recycling initiatives, yet contain many serviceable components and parts.

Our work builds upon two distinct practices which are addressing the role of the everyday consumer in utilising emerging technologies for their own social and cultural benefit. Proboscis has been developing the Urban Tapestries [lane] software platform since 2001 to allow people to annotate geographic places with multimedia information and share it among their fellow citizens through mobile and wireless technologies. At the same time, there has been increasing interest in developing adaptations of toy robots to sense environmental pollution (chemical, noise or radiation) – turning toys into tools of social activism.

In recent years there has been considerable interest in location based services and their integration into consumer mobile and wireless networks. Urban Tapestries has been one of the first platforms enabling content to be created and shared by ordinary users (as opposed to consumers accessing ‘pre-authored’ content served to them by network providers) – we are now investigating what the possibilities are for people to use these public authoring tools to affect their everyday environment.

In this paper, we report on two aspects of our work: the design and development of a low-cost mobile wireless sensor node developed using commodity materials and its integration with the Urban Tapestries server; and community workshops involving local citizens of the London Fields area in London. The designs of the system are made available as open source software and hardware.

RFPA PROJECT

What environmental factors such as air quality, noise and light pollution affect our neighbourhoods? How can we measure pollution in our own localities and make this data visible? How can we make sense of this in the context of what we already know about the places we live, work and play in? Robotic Feral Public Authoring links together two branches of research for community fun and action. Hobbyist robotics and public authoring both enable people to use emerging technologies in dynamic and exciting new ways. Brought together they open up whole vistas of possibilities for exploring our local environments with electronic sensors to detect all kinds of phenomena and map them using online tools.

Electronic sensors are now cheaply available for detecting a wide range of phenomena such as carbon monoxide, nitrogen dioxide, solvent vapours, electro-magnetic emissions (mobile phone masts, electricity generators etc), light and noise pollution. These can be combined with other cheap electronics (such as toy robots) that engage people in evidence collecting in a fun and tactile way. Adding the sensor readings to online mapping tools, such as Urban Tapestries, suddenly brings the relationships between environment and home vividly to life. It enables people to feel they can learn about their environment and have the evidence to do something about it. By linking robot building and mapping workshops into traditional community events (village fetes and local festivals) a wide range of people can become involved in gathering and sharing knowledge about their environment.

We set out to investigate how toy robots can be augmented with environmental sensors and used to map pollution by grassroots communities. In the Feral Robots project [jeremijenko] we have reconfigured low cost toy robots into vehicles of social and cultural activism, exploring how robotics could break out of the academic lab and how sophisticated equipment could be put into the hands of the general public by using the economies of scale of consumer manufacturers. In our current work we have designed and implemented a new generation of this technology and the software needed to enable it to sense pollution, add GPS location data and feed this back to the Urban Tapestries mapping platform.

Figure 1. The prototype mobile sensor network node with carbon dioxide and air quality sensors.

LONDON FIELDS AND COMMUNITY MAPPING

London Fields is a popular local park in Hackney, East London. Bounded by Richmond Road to the north, not far from Mare St (Hackney's busiest road) it is an important resource for local communities in a built up area. The park is used by local people for a variety of activities; as a space to play and socialise in (with two children's play areas), organised cricket and football matches, and many dog walkers. It is also a popular walking and cycle route. As part of a global city, London Fields and the area around it is constantly hanging, adapting to accommodate the differing needs of the surrounding population. London Fields' origins first recorded mention in 1540) and its existence today related to its use as Lammas land, an area for communal grazing. It was the last piece of common land for livestock on a drovers route from Essex to London Town before being herded off to 'Slaughter Street' off Brick Lane or East Smithfield.

Currently the intervention of property developers in the London Fields locailty is raising serious concerns about the gentrification of the area and the impact this will have on local communities. During the 19th century the Fields themselves were under threat and only just survived a number of attempts to change their use. In the 1860s agents for landlords began promoting the site for development, dismissing the Lammas rights as rarely used and pointing to the neglected state of the fields. The importance of London Fields location as large open space so close to the city was recognised, and thus development not allowed. London Fields became a public park in 1872.

London Fields was selected as the location for this experiment because of its strengths as a public space used by distinct communities. Collaborating with SPACE Media Arts enabled the utilisation of their local community networks. A group of 15 participants took part in a community pollution mapping exercise in London Fields in November 2005. In small groups, participants explored London Fields equipped with audio devices, digital cameras and Pollution Sensing eNotebooks to look for evidence of pollution. Information gathered was mapped on to a large aerial photograph of the area and became a starting point to explore wider concerns about pollution (both visible and non visible) and the potential application of technology by communities to detect it.

> 'In London we have the highest level of asthma in the world. There must be a reason for this. If people don't have the tools they can't make this jump... to enable them to visualise the pollution that they in part cause'
>
> 'As soon as the word pollution is mentioned, one is made to feel like something is under threat or being destroyed.'
>
> 'If we encourage people to map pollution in their area they suddenly think their area is polluted.'
>
> 'Most peoples homes are more polluted than the outside space we occupy, through chemicals in furniture, upholstery and construction materials such as MDF.'
>
> 'Living close to London Fields I would like to be part of an experiment which maps pollution in London Fields inch by inch... we need to know where it is polluted and then we can start to put up signs and warn people'.

Figure 2. Local participants at the first community workshop on Robotic Feral Public Authoring.

Or perhaps not:

> 'The more I think about it, the less I want to have any access to any data about air pollution in my locality, or information about this park. I don't have a garden, I have a kid, I'll always use it.'
>
> 'we have come to accept air pollution because we are culturally habituated in it... that's got to change and if this doesn't happen at a grass roots level with tools that we can handle ourselves governments will not shift because they are in with the big corporations'

So is community pollution mapping about producing accurate scientific data? Or is it a tool to highlight concerns, to map knowledge and collect data to reinforce perceptions of an area. We aim to investigate how can activities like hobbyist robotics and public authoring help local communities come together to explore and act on the environmental evidence they collect.

TECHNICAL DEVELOPMENT

The Feral Robot system follows the standard client/server pattern employed in all clients within the Urban Tapestries (UT) public authoring system. One or more feral robots act as clients sending real-time data to a UT server. This geo-referenced, environmental data is written to a database for later retrieval via a web interface.

The first generation of feral robots was developed using the very low cost PIC microcontroller family which provides computing power roughly equivalent to that of a remote control. The requirement for location annotation and wireless and internet connectivity for the new version implied that an altogether new design was required. We also wanted to be able to support a more extensive collection of sensors, several of which required an extended period of warm-up. For this reason, we designed a new printed circuit board that provides several advantages:

1. *Provide power to the gusmtix stack assembly*: The processor board and its peripherals required a clean 5V supply in order to feed their internal 3.3V regulators. It was not clear how much current would be required though. Experimentation with the prototype showed that a current of 800mA would be required. This meant that the use of a switch mode power supply circuit would not be necessary as its linear alternative was much simpler and lower cost to implement. In practice the line regulation provided was satisfactory, but the solution led to two problems: the regulator generated a lot of heat, and the internal Hirose connector provided a rather high impedance path to the supply current. The large amount of heat generated was dealt with the choice of a bigger heatsink. A heatsink with a thermal resistance of 3.7 degrees per dissipated watt was finally chosen, thus ensuring the reliable operation of the circuit beyond the winter months. The relatively high impedance of the Hirose connector manifested itself through unexpected resets occurring during the power-up sequence of the wi-fi card. A sudden drop to the overall supply voltage activated the reset circuit of the processor. The solution to the problem was to distribute the current to the power hungry parts of the assembly via an external wire. In this way, the supply by-passed the Hirose connector and the voltage drop was minimised.
2. *Provide power to the sensors:* Power to the sensors was provided by a second linear regulator. Because the overall power consumption was within the limits of the regulator (less than 1A), the same heat dissipation solution was applied as in the case a, above. A fuse was provided towards the sensor boards in order to avoid any problems that might have been caused by a short circuit occurring on the external load.
3. *Charge and maintain the battery cells*: The choice of batteries was rather limited to NiMH cells due to their good performance/price ratio. Their weight was not an issue so Li-based options were ruled out. A constant current source providing charging current to 1/10 of the capacity was formed. Their capacity (2000mAh) would provide enough charge for a significant number of readings to be sent to the server, but would not provide the necessary power for the sensor warm-up period. The circuit would have to be powered by the external wall transformer during that period. A fuse was included towards the battery connection so as to protect both the battery and the PCB from any potential short circuits.
4. *Provide serial console access to the gumstix system*: The robostix brings out the gumstix console port on a 4-pin header. This port is a TTL level signal, so a standard TTL to RS232 level signal translator was used. No special protection was built into the circuit as the console port was expected to be connected directly to the PC within a rather well protected environment.
5. *Form the mechanical host of the gumstix stack*: The overall mechanical assembly of the heatsinks, the terminal block connectors and the processor boards was quite heavy. A final choice of epoxy glass PCB was made in order to cope with the weight.

The heart of the new design is the Gumstix small form factor system [gumstix], measuring 80 *20x6mm, which incorporates the Intel Xscale network processor and supports an embedded Linux distribution including a full implementation of the IP stack. A summary of the hardware setup follows:

1. *Linux-based system*: gumstix connex 400xm-bt single-board computer with stackable add-on boards for extended I/O capability, running the main feral robot client application.
2. *Environmental sensors*: Figaro AM-4-4161 (carbon dioxide gas concentration evaluation module) and Figaro AMS-2100 (air quality sensor), attached to ADC pins on the robostix add-on board. Sensor readings from these sensors are converted to digital measurements via the robostix data acquisition board (par of the gumstix platform) which includes a 10-bit analogue to digital processor.
3. *GPS receiver*: external Bluetooth device, wirelessly linked to main gumstix system (in our prototype we used an OEM version of the Socket BT receiver).
4. *Wireless TCP/IP networking*: Netgear MA701 wi-fi CF card, connected on gumstix netCF add-on board.
5. System integration: The above components are assembled and fixed on top the custom-built electronic circuit board and a battery power supply; finally, the package is mounted independently on top of an remotely controlled all-terrain R/C vehicle at 1:14 scale.

In particular, the following gustix modules where used: (i.) connex 400xm-bt main processor board with Intel XScale processor with maximum clock frequency of 400MHz, 64 MB of RAM, 16MB of flash memory, and a Bluetooth interface; (ii) robostix add-on board featuring the AVR ATmega128 microcontroller unit with analog-to-digital capability (10-bit, 8 channels) and (iii.) netCF add-on board with integrated Ethernet port and CompactFlash slot.

The following sensors from Figaro [figaro] where used:
1. *Figaro AM-4-4161*: an evaluation module (with on-board microprocessor to linearise readings) for the TGS-4161 carbon dioxide (CO2) gas sensor. The module's output range is 0.0 to 3.0V corresponding to a gas concentration of 0 to 3,000 ppm.
2. *Figaro AMS-2100*: a pre-calibrated air quality gas sensor module. The output range is 0.7 to 2.5V.

Obviously, the choice of sensors in RFPA implementations will depend on the type of pollutants to be detected or measured in each case. Up to eight different inputs can be attached in this prototype's setup.

Finally, the feral robots require wireless internet connectivity to access the UT server. Although the current version can connect to any open wireless LAN, a mesh network infrastructure provides maximum coverage and flexibility. In the London Fields outing we used a portable WiFi mesh node from Locustworld.

The gumstix hardware platform is supported by customized GNU/Linux distribution based on the Buildroot system which provides a set of make-files and patches that facilitates the generation of a cross-compilation tool-chain and root file-system for a target Linux system using the uClibc C library. The evolution of the gumstix distribution is maintained under version control with Subversion (this repository is hosted at http://svn.gumstix.com).

To develop applications for gumstix platforms a Linux-based host system is used with a fully-featured GNU software development environment properly set up, including the Subversion tools. Alternatively, Microsoft Windows with COLINUX can be used as host system for gumstix development. The host must be connected to the Internet in order to interact with the Subversion repository and download software packages during the build process.

There are several ways to gain command-line access the GNU/Linux system on a gumstix, but the most powerful (as it also allows access to the boot-loader) and failsafe is usually via the serial console. For this, the host computer must be connected to the gumstix's serial console port with a null-modem cable. The default parameters for the serial terminal emulator on the host should be the following: 115200 bps, no parity, 8 data bits and without flow-control.

Besides the main gumstix buildroot development trunk, a structure is defined in the Subversion repository for branching different buildroot configurations to meet or implement a specific project's requirements. Several branches can coexist in the repository and be developed independently in parallel, while changes can be merged back and forth between branches or the main trunk. For the feral robot prototype such a branch was created on the gumstix hosted Subversion, not only to track modifications to the custom buildroot's configuration, but mainly to ease the process importing bug-fixes or new features developed in the main trunk (after the branching has occurred). This allows great flexibility and availability to the software developed; for example, simple build commands can be used to download and build a working copy of the customized "Feral Robot" buildroot branch, including the extra software for the robostix board (further described in Robostix ADC).

There is no analogue to digital conversion (ADC) capability directly available on the main gumstix processor board. Thus, the robostix add-on board was used in this prototype, due to the ADC functionality present in its AVR ATmega128 microcontroller. The gumstix and robostix boards are interconnected via their serial ports making data exchange between software running on both processors possible. This feature is exploited to give the feral robot client application (running on gumstix) access to sensors attached to any ADC channels of the robostix.

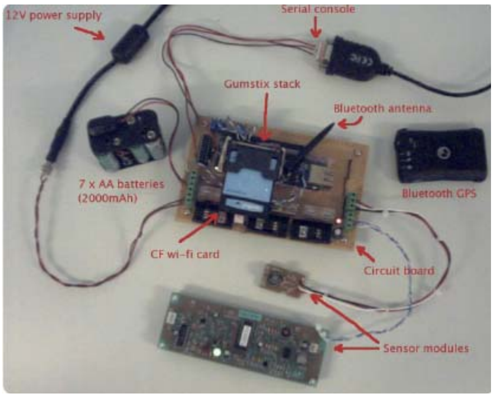

Figure 3. Assembling the Feral Robot hardware.

In essence, the communication protocol on the robostix side consists of waiting for incoming ASCII characters on its serial port, that represent ADC channel numbers (from `0' to `7'), and responding with the current voltage value on that ADC channel, in hexadecimal format encoded as an ASCII string (e.g. "0 *03f9"). On the robostix's ATmega128 this function is implemented with an endless loop using native C. After compilation, the resulting binary file must be programmed (i.e. flashed) to robostix. Several possible methods to program microcontrollers of the AVR family do exist, and in this case the most straightforward way of doing this is to take advantage of the gumstix/robostix serial interconnection setup to perform in-system programming (ISP) of the software image, directly from the GNU/Linux system running on the gumstix: the binary image file must be transferred from the host computer to the gumstix by console (Kermit) or network (SSH), and then (on the gumstix) use the uisp command-line tool.

The utrobot application forms the core of the current feral robot behaviour--sampling its attached environmental sensors, reading the GPS position and sending data to the UT server. This application requires TCP/IP access to an active GPS daemon (gpsd), either running locally (default) or over a network connection.

Also the serial port of the robostix may have to be specified to access the sensors. Finally, the robot id (MAC address) and remote UT server address must be specified on the command-line--on the gumstix this is done by a wrapper script.

Collecting and processing the data sent from the Feral Robot required a series of extensions to the existing Urban Tapestries backend system to fit with the special needs of the robot client. A separate server component was designed and implemented that establishes connectionless communication with the robot. This accepts the robot's data packets which contain the robot's GPS position along with the corresponding value of each sensor measurement and the time this measurement was taken. After extracting the packet contents they are stored in the database, from where they become available for processing and visualisation.

A very simple UDP-based protocol was devised for communication between the feral robots and the UT server. Basically the clients are programmed to periodically sample their sensors and the GPS receiver and, for each reading, packages the data into a UDP datagram, that is then sent to the server. The protocol, in its version 1, defines a packet structure with the following data fields:

  * Status information
  * Client identification (MAC address)
  * Latitude/Longitude
  * Time stamp
  * Sensor type and value

The initial visualisations of the feral robot sensor data were made by processing a static high quality aerial photo of the area in which the measurements were taken, and overlaying it with an extra transparent image layer. The sensor values and each reading's position were fetched from the database, associated with a colour from the visible spectrum, and then drawn onto the image layer as a dot with diameter equal to the maximum GPS position deviation. This forms a dense coloured "cloud" over the subject area (cf. Figure 4).

Our next stage was to develop a dynamic mapping representation using Google Maps and associating the sensor data with other contextual knowledge in the Urban Tapestries web interface. The Google Maps API makes it possible to overlay information onto a detailed map by placing markers, drawing lines and linking information to latitude and longitude co-ordinates. The API provides a series of commands for adding markers, information windows and events to a Google Map embedded in a web page. It also offers a way to link to external information stored on a server via the GXmlHttp command. Information returned by a GXmlHttp call can then be used to update the map, the graphical overlays on the map and the associated information. AJAX (Asynchronous JavaScript and XML) allows us to make this update without needing to reload the entire page. Information sent to a server via this command can be stored and retrieved the next time the map is accessed by a client.

As well as displaying location-based information spatially, the Google Maps API detects user events like dragging the map. Along with the Google Maps control panel for controlling zoom level, this provides the viewer with many options for browsing. When the map is clicked on by a viewer, the map detects this event and returns the co-ordinates of the click as latitude and longitude. This provides a way for viewers to add their own location-based information to the map.

The feral robots sensor data contains latitude and longitude for each sensor reading, which is uploaded to the UT server and can be called and displayed in the UT web interface. The GXmlHttp command returns the .gpx file generated by the UT server from the sensor packets uploaded by the feral robots, from which the relevant information is extracted to represent the robots findings. The feral robot takes readings every two seconds, resulting in an average of seven hundred readings per sensor per trial. As the performance of Google Maps is reduced when displaying a large number of markers simultaneously the UT web interface only represents every other reading with a marker on the map. These markers are linked with a GPolyline illustrating the path the robot followed when making the readings. The colour of the marker represents the level of the sensor reading.

In a separate call to the server all UT threads labelled with an 'environment' tag are requested, which are also displayed on the sensor readings map. As the Google Maps API enables custom markers to be used, the UT web interface can visually differentiate between the UT threads and sensor readings.

DISCUSSION AND APPLICATIONS

In the two years since we formulated the project we have seen its emphasis shift from `pollution mapping' to what we now describe as `everyday archaeology'. Our vision has been informed by the process of working on a site with local people, many of whom were concerned for their environment, but for whom the initial focus on pollution proved questionable. Gathering data on environmental phenomena such as pollution was seen as a major benefit for local people to campaign around, but others saw it more as a valuable creative activity in itself.

Electronic sensors are now cheaply available for detecting a wide range of phenomena such as carbon monoxide, nitrogen dioxide, solvent vapours, electro-magnetic emissions (mobile phone masts, electricity generators etc), light and noise pollution. These can be combined with other cheap electronics (such as toy robots) that engage people in evidence collecting in a fun and tactile way. Adding the sensor readings to online mapping tools (such as Urban Tapestries) suddenly brings the relationships between environment and home vividly to life. It enables people to feel they can learn about their environment and have the evidence to do something about it.

We think that the greatest potential for Robotic Feral

Public Authoring lies in linking robot building and mapping workshops to existing community events such as village fetes and local festivals. This idea of embedding the practice into familiar rituals offers opportunities for involving a wide range of people in gathering and sharing knowledge about their environment. Through the concept of everyday archaeology Robotic Feral Public Authoring can tap into popular interests and past times – not only those of robotics hobbyists, but amateur historians and environmentalists.

Learning Games. The use of Robotic Feral Public Authoring as a tool for learning also represents a significant potential benefit. With some further technical refinement to make the `adaptation' of toy robots more accessible to people without specific electronics and engineering skills, and the creation of materials like activity and lesson plans, the project could quickly move into formal and informal education settings.

The benefits of this are multiple: from bringing children and other learners into direct contact with practical skills of making and building technologies and the representation of the data they collect; to stimulating the commercial production of new learning aids that are designed to enable people to develop their own creativity and analytical and communication skills.

It is possible to see that, just as the choice of toy robots was inspired by the ability to use the economies of scale of the toy industry to put sophisticated electronics into the hands of the general public, so Robotic Feral Public Authoring could inspire toy manufacturers to develop cheap `feral robot' adaptation kits. This could amplify the effect of the economies of scale whilst encouraging a generation of people to be co-creators, not just consumers of toys designed simply to entertain. Robotic Feral Public Authoring offers exciting new ways for electronics manufacturers and network providers to allow their customers to use their products in a socially and culturally enriching way – enabling new dialogues to be explored between industry and the people they create products for.

The greater the emphasis on participation at every level of society and culture, the greater the diversity of voices, ideas and knowledge can be contributed to society at large. Stable and healthy democracies are the product of wider participation and sense of responsibility. The vision of Robotic Feral Public Authoring is to contribute to a greater local sense of empowerment and impact of local people on environmental issues. It seeks to act as a model for how artists and engineers can collaborate to bridge the gulf between pragmatic technical solutions to social problems and the cultural interventions that artists bring to their communities. It is political is the sense that it inspires people to act; to investigate and collect evidence and use it to affect change.

This project has demonstrated that it is possible, using cheap electronics and publicly accessible mapping solutions, to create an exciting and engaging new form of environmental sensing at a very local level. Although our prototypes require a level of electronics and engineering skill above that of most people, it is well within the realm of the hobbyist and will not require a huge step to reduce the complexity of creating a feral robot even further as new platforms and products (such as motes) become more readily available and cheaper.

The next stage for Robotic Feral Public Authoring is to make this transition, focusing not only on the technical but, more importantly, on the social, cultural and educational uses and techniques needed to add the sense of purpose and context to environmental sensing. Designing the activity materials, whether for schools running geography and science projects, or campaign tools for environmental activists will provide the impetus for adoption and adaptation of the project's vision. Over the next few years it is easy to imagine a growing network of hobbyist data collectors springing up to help map our environment, learn about our effect on it and take action.

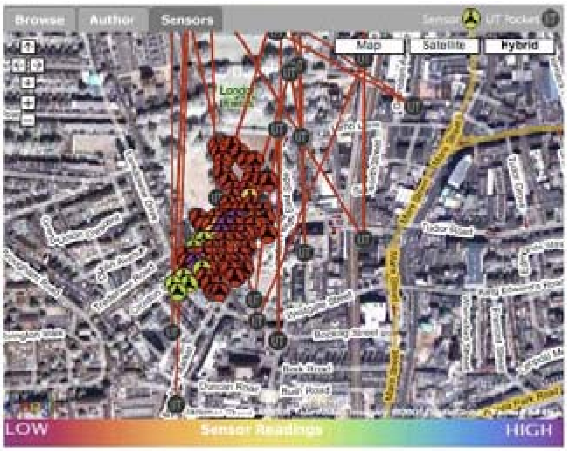

Figure 4. A visualisation of the data collected during the first London Fields trial.

ACKNOWLEDGEMENTS

We thank EPSRC for funding this work via its Cultural & Creativity Programme.

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