Carbon Metric Collection and Analysis with the Personal Environmental Tracker

Robert S. Brewer
University of Hawaii
Ubiquitous Wireless Applications Group
Laboratory for Interactive Learning Technologies
Department of Information and Computer Sciences
1680 East West Road, POST 309
Honolulu, HI 96822, USA
rbrewer@lava.net

ABSTRACT
The Personal Environmental Tracker (PET) is a proposed system for helping people to track their impact on the environment, and to make changes to reduce that impact, creating a personal feedback loop. PET consists of sensors that collect data such as home electricity or gasoline usage and send it to a database for analysis and presentation to the user. By collecting data from diverse sources, PET can help users decide what aspect of their lives they should make changes in first to maximize their reduction in environmental impact. PET's open architecture will allow other ubiquitous sustainability researchers to leverage the infrastructure for research in sensors, data analysis, or presentation of data.

Author Keywords
Ubiquitous computing, sensors, environmental change, mobile devices, social networking, feedback loop.

ACM Classification Keywords
H5.0. Information interfaces and presentation (e.g., HCI): General. K4.2 Social Issues.

INTRODUCTION
It is widely recognized that the global climate is warming due to anthropogenic sources [7]. There are an increasing number of people interested in making personal changes to reduce their contribution to climate change. We focus our efforts on these people who are actively seeking to reduce their carbon footprint. These users have questions about how best to direct their efforts, such as "how much additional electricity does increasing the thermostat on the air conditioner by one degree consume?" or "how much less carbon is released by carpooling with someone who lives nearby rather than driving alone?" We need to provide a system that allows users to perform informal experiments related to their daily lives and provide rapid feedback on the results of those experiments.

Another important question these users face is "what are the relative contributions of different activities to my carbon footprint (driving, air travel, heating/cooling home, entertainment, food, consumer purchases)?" While tracking usage in individual areas (home electricity usage, automobile gasoline consumption) is important, the comparative contributions to the user's carbon footprint must be determined for rational decision–making. This approach allows users to prioritize among the many possible ways they can reduce their environmental impact.

SYSTEM DESCRIPTION
Our proposed system, the Personal Environmental Tracker or PET, will help users reduce their footprint in three steps: collecting data about their daily activities, converting the raw data into a carbon footprint, and embedding the results in social networks, forming a feedback loop for environmental change.

Sensors
PET will collect data about users' lives through a constellation of sensor inputs. While our target users are already motivated, it is critical that the effort required to collect data is kept as low as possible. Many people live busy lives, and excessive overhead for data collection may convince users that collection is not worth the effort, especially when the environmental results might not be seen for decades. We see several ways to collect data: physical sensors, information sensors, and manual sensors.

Acquiring data from physical sensors is a commonly used method. For example, systems for tracking electricity usage for a whole house [4], or a single device [9, 8] already exist. Positional data from GPS units (such as those in some smartphones) can allow estimation of carbon output based on mode of transportation such as the Carbon Hero system [5]. One could even imagine a tailpipe sensor attached to an automobile that directly tracked greenhouse gas emission.

The disadvantage of physical sensors for data acquisition is that it often requires the purchase and installation of equipment to collect the data or extract it in digital format. The exceptions are sensors that piggyback on an existing device, such as the GPS capabilities of a mobile phone already carried by the user.

Calibration of the sensor data is an important topic to address because data can be collected from number of different types of physical sensors under varying circumstances. Because PET will have raw data collected from users with different sensors, the accuracy of sensors can be compared for users performing similar activities. Users with access to different sensors of the same type (such as whole-home electrical usage) could use both sensors simultaneously to gauge their accuracy and compare them to the values provided in the bill from the utility company. For sensors where each instance has a variable degree of error, users could be directed to a standardized trial (such as walking between two points for calibrating a location sensor) and the results compared to results from other users.

An increasing amount of relevant data is already available online; it merely needs to be mined and processed to be useful to PET. We call these sensors that gather data from digital sources *information sensors*. One area with abundant data is credit or debit card transactions. Those users who make most purchases with credit cards possess a wealth of information that can provide data on environmental impact, such as buying gasoline, food, or consumer products. Personal finance web applications such as Wesabe (http://www.wesabe.com/) have demonstrated that it is possible to securely make use of credit and debit card transaction information to aid users in tracking their finances. Retrieving electricity usage data from utility websites is another source of data already being used by systems such as Personal Kyoto (http://personal-kyoto.org/). PET can also leverage the data users are voluntarily maintaining online, such as travel itineraries in the TripIt web application (http://www.tripit.com/).

To reduce overhead for users, automation is generally preferable to manual data entry. In some cases, however, users will need to take explicit action to record data for PET. We believe mobile devices can significantly reduce the effort required for manual entry, and allow the data capture to happen at the time and place of event being recorded. For example, mobile phones can scan RFID tags containing the carbon footprint of products that manufacturers may embed in the future [1]. Cameras in mobile devices can capture the ubiquitous barcodes on products, or scan receipts for later analysis by optical character recognition. Speech-to-text services such as Jott (http://jott.com/) can provide for hands-free data entry, and of course, users can always fall back to typing into their mobile device.

Analysis

As data are collected, PET can provide a variety of analyses. One particularly useful analysis would be to condense the data down to a single number representing the user's carbon footprint. A single value would allow the user to easily see how their behavior is impacting the environment, and allow comparison with other people and groups.

It is important that the feedback and analysis of the user activity be as immediate as possible. For effective behavior modification, the delay between action and understanding its impact should be short, measured in minutes or hours, not days and weeks as most utility bills are.

Calculating the carbon footprint of activities requires the use of estimates and averages for some factors. Because the best guesses for these values may change over time, or there might be differences of opinion on how best to compute the footprint, we propose making the analysis methods user–modifiable, further permitting users to participate in the scientific process. To permit comparison and aggregation of footprint data, there will be a canonical calculation formula that will be updated over time as better techniques become available. Users can modify the canonical formula to perform "what if" calculations on their own data, and share their formulas with other users for discussion.

PET only displays the results and analyses of users' actions, and does not prescribe how users should modify their behaviors. The aggregation of sensor data from multiple aspects of users' lives ensures that they can see what behavior changes make most sense for them.

Social networks

Allowing users to go beyond just looking at their own footprint, to see it in context with other users' can be an important way to motivate change in the long term. Comparisons with friends, neighbors, and others around the world can give users the motivation to continue to or redouble their efforts. Friendly competition can be helpful, but it's important that the desire to improve one's standing through manipulation of sensor data not get in the way of the underlying goal of reduced environmental impact.

Integration into social networks can facilitate users sharing knowledge about how to reduce consumption, and emotional support from like-minded individuals.

SYSTEM ARCHITECTURE

To support the range of functionality described above, we envision the architecture of PET as a multi-tiered system using HTTP and representational state transfer (REST) [6] to tie the components together. Figure 1 shows a block diagram of the system architecture. Sensors are device or service-specific plugins that collect data and send them to a

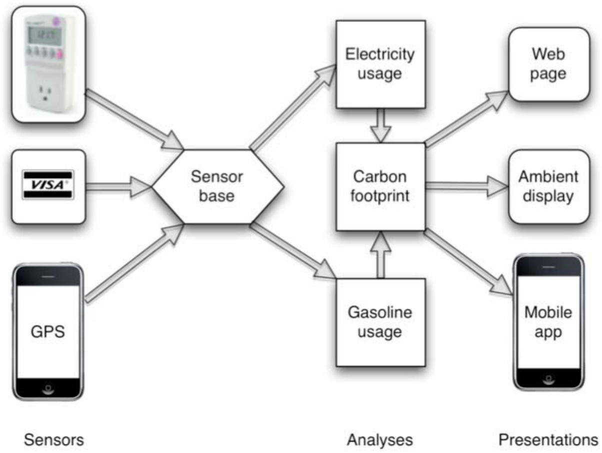

Figure 1: PET system architecture

sensor database. The sensor base component simply stores data for later recall by analysis tools. Analysis tools retrieve sensor data from the sensor base, and in some cases, pass their results to higher-level analysis tools. For example, sensor data about gasoline usage in the sensor base might be converted to an estimate of greenhouse gas emissions, which could then be used to compute the relative contribution of gasoline usage to the user's carbon footprint. Presentation tools can take up the results of these analyses for display as web pages, to virtual polar bears [3], or interactive games [11]. In fact, the social network functionality discussed earlier could be built as an application for existing social network systems (such as Facebook or Orkut) that is just another presentation tool for data in the sensor base.

PET strives to be as open as possible. The use of HTTP and REST allows sensors, analyses, and presentation tools to be implemented in any language. Standardized formats for sensor data will allow easy implementation of new sensors, and decouple sensor development from analysis and presentation. Tracking a new type of activity only requires the creation of a new sensor that talks to the existing sensor base. All the existing analyses can be applied to the new data source. Experiments on new persuasive computing techniques to change user behavior can be structured as new analysis and presentation tools on top of the raw sensor data or lower-level analyses.

The system will be open source, enabling a broad development community to take shape. In particular, having an open source sensor base allows organizations that wish to collect data but do not want it to be public, to set up their own servers for internal use.

Most users would send their data to a centralized default server open to the public. In PET, users will own their data: they should be able to download their data, move it elsewhere, or remove it from the system entirely. The personal finance site Wesabe was a pioneer in this area with their users' "data bill of rights"[1], which applies equally well to the environmental data we intend users to collect.

The spectrum of data that PET collects on the user's environmental impact is potentially quite private (location traces, travel history, etc.) and some users may not wish to share their data. The raw data are required for accurate analysis; however, for discussion and sharing among the user's social network, only the aggregated values resulting from the analysis are required. A public PET server can collect data from all users, but it only allows users access to their own raw data. The server can distribute aggregated data and the results of analyses among users without unduly intruding into users' privacy. For those users who are unwilling to entrust their raw data to a public server, an option to create a personal analysis system that runs on the user's computer can be considered, optionally sending the results of the analyses to the public server for aggregation.

INITIAL IMPLEMENTATION

The initial implementation of PET should provide the entire workflow from data collection to analysis and presentation for two different types of sensor data. The APIs and data formats used by the sensors and the sensor base need to be well defined to support additional development by external developers. This infrastructure would allow an initial evaluation of our claims about the utility of having sensor data from different aspects of daily life merged into a single presentation.

Once the initial implementation is complete, we would seek to build an open source community around the system to support more sensor input types and more analysis and presentation tools.

CONTRIBUTIONS

The idea of recording data about people's lives and tracking trends to help reduce their environmental impact has been thought of before [10]. PET differs from previous work in this area by offering a comprehensive open framework for this endeavor. PET would provide infrastructure for other researchers in both data collection and analysis, potentially speeding progress. Researchers working on new analyses or persuasive presentations of data could focus on the analyses rather than having to also spend their time constructing a system for collecting sensor data. Researchers developing new sensor inputs would have a natural destination for their data that allowed them to perform useful analyses.

Since PET will collect data in multiple aspects of users' lives (electricity usage, gasoline usage, etc), it can provide useful information on the meta question of what area a user should focus his or her efforts to reduce environmental impact. This approach differs from most systems that focus on only one area such as home electricity usage or carbon released from personal transportation usage.

[1] https://www.wesabe.com/page/security

In order to be useful, PET requires data input from sensors and analysis by computers, each of which create their own environmental impact. As described earlier, PET accepts data not only from physical sensors, but also information sensors and technology-assisted manual data entry. The sensors seek to leverage existing devices (such as mobile phones) and existing behaviors (such as personal financial tracking), which significantly limits the additional impact of data collection. A survey of studies on usage feedback systems in energy consumption found that savings on the order of 10% or more was quite achievable [2]. If PET can enable users to make a comparable reduction in environmental impact, the additional costs of data collection, analysis, and social collaboration will be quite small in comparison.

While we have focused on the issue of climate change, PET could easily be extended to track other sustainability topics such as water usage, habitat loss, and social justice through the creation of new sensor inputs and new analysis and presentation tools.

PET will provide its users with insight into their own environmental impact, and the impact of others in their social network. That foundation of understanding, based on hard data, provides the platform for advocacy and activism in their jobs and communities. PET users can speak from direct experience on how environmental impact can be reduced, and demand those reductions from their employers and their elected officials.

In the broader context, the data collected and experimentation with analyses could provide more accurate models for calculating carbon footprints when fine-grained data are not available. The results could feed back into policy decisions, which could be based on data gathered about how people actually live. Finally, users positive behavior modifications would have a direct impact on climate change.

BIOGRAPHY

Robert Brewer is a research assistant on the Ubiquitous Wireless applications team in the Laboratory for Interactive Learning Technology (LILT) at the University of Hawaii at Manoa. He is pursuing a PhD in the Information and Computer Sciences (ICS) department with a focus on ubiquitous computing and environmental awareness.

Robert graduated from Reed College in Portland, Oregon in 1992 with a Bachelor of Arts degree in Physics. In 2000, he received a Master of Science degree from the ICS department at the University of Hawaii at Manoa. His thesis research focused on improving mailing list archives.

Robert also has experience in industry. As one of the founders of LavaNet (a Hawaii-based Internet Service Provider), Robert also took an active management role as vice president and technical manager for the first three years of LavaNet's existence. Over LavaNet's 14-year history, he worked as a senior technical specialist on a variety of Internet infrastructure projects.

MOTIVATION

The Ubiquitous Sustainability workshop is closely aligned with the research area for my dissertation. Feedback from this workshop can further shape my ideas as I prepare my dissertation proposal. Learning the latest research directions from like-minded individuals will grow my knowledge of related work in this area.

REFERENCES

1. Dada, A., Staake, T., and Graf von Reischach, F. Displaying Dynamic Carbon Footprints of Products on Mobile Phones. In *Demo Session of Pervasive 2008*, (2008).
2. Darby, S. Making it obvious: designing feedback into energy consumption. In *Proc 2nd International Conference on Energy Efficiency in Household Appliances and Lighting*. Italian Association of Energy Economists, Naples, 2000.
3. Dillahunt. T., Becker, G., Mankoff, J., and Kraut, R. Motivating Environmentally Sustainable Behavior Changes with a Virtual Polar Bear. In *Workshop Pervasive Persuasive Technology and Environmental Sustainability*. Pervasive 2008, (2008).
4. Energy, Inc. The Energy Detective. http://www.theenergydetective.com/.
5. European Space Agency. Tracking your carbon footprint. http://www.esa.int/esaCP/SEM7MVVHJCF_index_0.html
6. Fielding, R. T. and Taylor, R. N. Principled design of the modern Web architecture. *ACM Trans. Internet Technol.* 2, 2 (May. 2002), 115-150.
7. Intergovernmental Panel on Climate Change. IPCC Fourth Assessment Report: Climate Change 2007, http://www.ipcc.ch/
8. LeBlanc, J. Device-Level Power Consumption Monitoring. In Workshop on Ubiquitous Sustainability, UbiComp (2007).
9. P3 International. Kill-A-Watt. http://www.p3international.com/products/special/P4400/P4400-CE.html
10. Sutaria, R., Deshmukh, A. Taking the Guesswork out of Environmentally Sustainable Lifestyles. In *Workshop Pervasive Persuasive Technology and Environmental Sustainability*. Pervasive 2008, (2008).
11. Takayama, C., Lehdonvirta V. EcoIsland: A System For Persuading Users To Reduce CO2 Emissions. In *Workshop Pervasive Persuasive Technology and Environmental Sustainability*. Pervasive 2008, (2008).