

HomeLab: A Platform For Conducting Experiments With Connected Devices In The Home

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1. INTRODUCTION

The downward spiral in the cost of connected devices and sensors (e.g., cameras, motion sensors, remote controlled light switches) has generated a vast amount of interest towards using them in the home environments. Companies and researchers are developing technologies that employ these devices in a diverse range of ways. These include improving energy efficiency, increasing comfort and convenience through automation, implementing security and monitoring, and providing in-home healthcare.

However, conducting experimental work in this domain is extremely challenging today. Evaluating the effectiveness of research prototypes typically requires some form of deployment in real homes. This task is riddled with not only social and legal constraints, but also logistical and technical hurdles. Examples include recruiting participants, hardware and software setup in the home, training participants and residents who typically possess varying levels of technical expertise, and diverse security and privacy concerns. Because of these challenges, individual research groups rarely manage to deploy their prototypes on more than a dozen or so homes concentrated in their geographic area. Such deployments tend to lack the scale and diversity that is needed to confidently answer the research hypothesis.

Our goal is to lower the barrier towards deploying experimental technology in a large number of geographically distributed homes.

Categories and Subject Descriptors

H.1.2 [User/Machine Systems]: [Human Factors]

General Terms

Design, Experimentation, Human Factors, Management

Keywords

Home automation, smart home, domestic technology, devices, test beds

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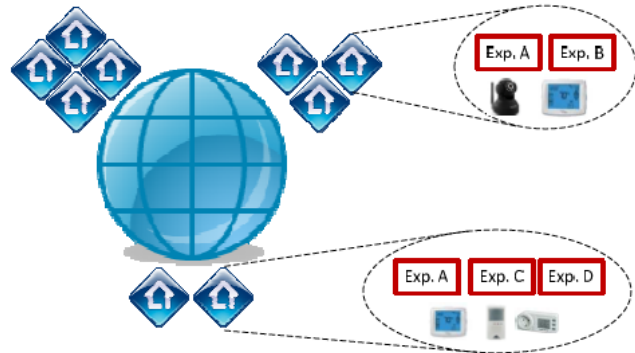


Figure 1: HomeLab will consist of multiple sites across the world, each with multiple homes recruited and managed by a research group.

We are inspired by PlanetLab, which enabled the development and evaluation of global network services. Analogously, we are developing a shared infrastructure for home environments, called *HomeLab*. We envision HomeLab to comprise of a large number of homes in various parts of the world, where each home hosts a common framework, in which experiments can be run (illustrated in Figure 1). Individual research groups that participate in HomeLab recruit and manage dozen or so homes. They can then run their experiments on other groups' homes in exchange for letting others run experiments on their homes. The vision and rationale of HomeLab was outlined in a workshop paper last year [1].

Since then we have made significant progress on its design and implementation. Our initial design is guided by what we have found, based on our experience and by talking to other researchers, to be common tasks in deploying home technology. These include: (i) collection of sensor data for analysis by residents or researchers, e.g., energy or water consumption, or camera snapshots (ii) monitoring of sensors for decision making or actuation, e.g., adaptive heating control, or fall detection for seniors, (iii) collection of logs of users' interaction with sensors/devices. A common framework for such tasks would greatly simplify the effort needed by individual research groups and it would also enable code re-use and sharing of expertise.

This demonstration will illustrate the capabilities of HomeLab including: (i) the ease of hardware setup, (ii) the ease of application development for complex experiments involving multiple devices, sensors, and datastreams, (iii) the ease of remote experiment deployment, monitoring, and update, (iv) the ease of data collection, and (v) incorporation of dif-

ferentiated access to data and devices (e.g., to address participants' privacy concerns, obtain ethics board approvals). Our hope is to encourage researchers to become part of HomeLab and obtain feedback that will help us improve its design.

2. HOMELAB DESIGN

In HomeLab terminology, an *experiment* is a research application running (e.g., energy use monitoring, occupancy sensing) on a number of homes. To help conduct an experiment, HomeLab provides 1) a common framework to write applications, and 2) a set of capabilities such as updating applications and warehousing application data in one place.

We build on top of HomeOS [2] as a application-development framework. HomeOS provides a PC-like abstraction for in-home hardware and simplifies the tasks of writing applications and managing sensors. This framework decouples experiment-specific logic from the generic mechanisms and semantics required by, (a) researchers to robustly interact with in-home sensors, and (b) by participants to interact with sensors and their applications. This decoupling enables sharing and reuse of engineering effort, experiences, expertise in building in-home and supporting infrastructure, and possibly experimental data across research groups. Many research groups are already using HomeOS for developing research applications and course projects.

The set of supporting capabilities that are part of HomeLab include the following:

Effortless setup: Simplifying the often complex and tedious setup of sensors in a home, HomeLab provides a unified interface for a researcher or participant to setup and configure in-home hardware.

Simple experiment development: HomeLab maintains the benefits of homogeneity that HomeOS offers to application developers. For instance, an application can collect energy consumption data using various types of sensors while being agnostic to sensor-specific protocols (e.g., Zwave, Zigbee, or WiFi).

Extensible support for devices: HomeLab supports a wide range of off-the-shelf devices (e.g., many Zwave sensors, IP cameras) as in-home sensors, and provides mechanisms for new devices or prototypes to be added, used, and shared amongst the research community.

Remote experiment deployment: HomeLab provides researchers with robust mechanisms for advertising their experiments to potential participants, deploying, monitoring, and updating their experiments remotely, while preserving participants' preferences.

Data durability and access: HomeLab incorporates a *Home Data Store* which provides seamless transfer of application data to the cloud, and handles scarce in-home storage, and intermittent network connectivity. As a result, experimenters get reliable, low-latency access to their data, conducive for data analysis.

User security and privacy: Experiments involving end-user applications can easily incorporate robust user authentication and authorization. For instance, experimenters do not need to re-design parental control, guest access, out-of-home access to applications, or DoS prevention components in their applications.



Figure 2: Example in-home hardware.

Experiment scheduler A global scheduler is responsible for scheduling and running experiments based on the needs of the experiment (e.g., specific hardware or geographic location). The scheduler also needs to maintain isolation of experiments running in the same home. Our current experiment scheduler is simplistic, however. It fully dedicates a home to one experiment. We are trying to better understand experimental conflicts and their prevention.

Miscellaneous services: Experiments that may require other functionalities such as email, SMS, or IM notifications, can easily avail the respective pre-existing services offered by HomeLab while exerting little additional design effort.

3. IMPLEMENTATION AND STATUS

We have developed all of the capabilities outlined above. We have tested our current implementation with many off-the-shelf devices, .NET Gadgeteer¹ devices, using a moderately powered netbook running our in-home framework (HomeOS). Figure 2 shows such a setup consisting of a netbook, a Foscam IP camera, and Aeon Zwave door-latch, water-leaks sensors and power switch. Cloud services run on Microsoft Azure, to provide remote access for home user and experiment management for researchers.

4. REFERENCES

- [1] A. Brush, J. Jung, R. Mahajan, and J. Scott. Homelab: shared infrastructure for home technology field studies. *Proc. HomeSys*, 2012.
- [2] C. Dixon, R. Mahajan, S. Agarwal, A. Brush, B. Lee, S. Saroiu, and V. Bahl. An operating system for the home. *Proc. NSDI*, 2012.

¹<http://www.netmf.com/gadgeteer/>