Wireless Sensor Network Based Smart Home: Sensor Selection, Deployment and Monitoring

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Abstract – **The ubiquitous nature of miniature wireless sensors and rapid developments in the wireless network technology have revolutionized home monitoring and surveillance systems. The new means and methods of collecting data efficiently and have led to novel applications for indoor wireless sensor networks. The applications are not limited to solely monitoring but can be extended to behavioral recognition. This can be of great value with the elderly as it can allow anomalous behavior to be detected and corrective actions taken accordingly. This paper details the installation and configuration of unobtrusive sensors in an elderly person's house - a smart home in the making - in a small city in New Zealand. The overall system is envisaged to use machine learning to analyze the data generated by the sensor nodes. The novelty of this project is that instead of setting up an artificial test bed of sensors within the University premises, the sensors have been installed in a subject's home so that data can be collected in a real, not artificial, environment.**

Keyword: wireless sensor network (WSN), current sensor, water flow sensor, data visualisation

I. Introduction

The populations of the OECD countries are aging and more and more people are getting dependent on assisted living [1]. The escalation in the cost of human-supervised living is putting a huge strain on the government budgets. It is economically and socially advantageous to reduce the burden of medical expenditure by enhancing prevention methods and early detection of disease. Attempts have been made to shift from the centralized, expert-driven, crisis-care model to one that permeates personal living spaces and involves informal caregivers, such as family, friends, and community [2]. The advancement of sensor technology has enabled assisted living without human intervention, thus making it affordable for old people to live an independent life without encroaching on their privacy.

Assisted living requires that sensors provide live monitoring data of the activities of the subject and may trigger alerts if any anomalies are detected. Advancement of semiconductor fabrication technology and smart algorithms has made it possible to design and develop smart sensors with in-built intelligence [3]. For example, the electrical appliances usage sensor has been developed in such a way that it can monitor the time and duration of usage of different appliances with different power ratings. Similarly the water-use monitoring sensors use an inline flow transducer and the associated electronic circuit gives an indication of when water is being used. Davide Merico et al have developed the Safe and IN-Dependent living (SINDI) system, that focuses on monitoring people's quality-of-life and raising alarm under certain medical conditions. It uses wireless sensor networks (WSN) for data gathering, and logical methods for context interpretation and health assessment [4]. Assisted living test beds have been setup in several Universities around the globe to work with live data. Notable among them are the Smart Medical Home Research Laboratory at the University of Rochester [5], ALARM-NET, a Wireless Sensor network for Assisted-Living and Residential Monitoring [2] etc. The objectives of these research initiatives are to find, develop and improve the expressive, tractable and scalable techniques for modeling Activities of Daily Living (ADL) because older people with medical illnesses often have loss of independence in ADL [6].

In the context of monitoring the activity of an elderly person and using the data for pattern recognition, it is absolutely necessary that the sensors that will help to gather the data in an unobtrusive manner be identified. Recognizing human behaviour and detecting anomalies is very challenging because human behavior, even for the same individual, can vary widely. Typically, a person will wake up in the morning, get up, go to the bathroom and then make breakfast, perhaps using the toaster. However, these activities and their duration will not happen at exactly the same time each day and may have cyclic variations, such as with the seasons. The person may wake up later during the winter and spend more time in the shower during the summer. The sensors should be able to detect these activities, log the time and the duration of each activity. In this paper we describe the setting up of a smart home to gather ADL data which will be used for machine learning of behaviour and early detection of onset of diseases such as dementia.

II. System Description

This section gives a comprehensive overview of the types of sensors used, the network topology and connectivity as well as the type of data that are received by the central station (hub). The sensor nodes, the hub and the software interface have been provided by Monnit [7] which has a wide range of low power sensor modules that can be used for both household and industry applications. The Monnit wireless sensors, the Monnit Gateway, the Monnit enterprise server and the propriety sensor modules used in conjunction with the Monnit sensors are all

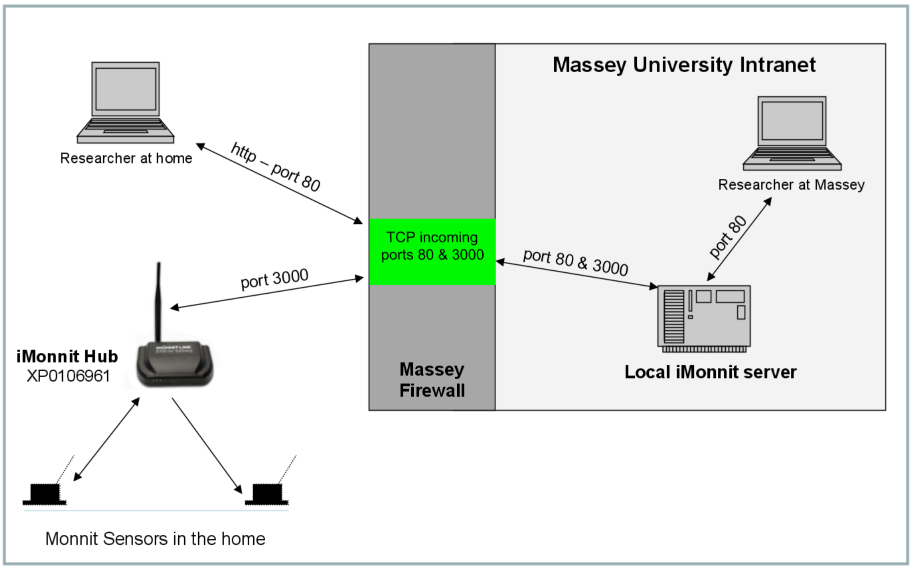

Figure 1. Monnit Sensor Network using Massey University based Monnit Enterprise Server

described. Figure 1 shows the sensor network arrangement with the Monnit Hub and sensor nodes installed at the subject's house while the iMonnit server is within the Massey University Intranet. The hub communicates with the server via a dedicated Internet connection that has been setup with the help of a local Internet Service Provider (ISP). A wide variety of sensors have been used. These include:

- temperature sensors
- lux sensors
- humidity sensors
- dry contact sensors
- magnet-based open/close sensors
- passive Infrared (PIR) sensors

A. *Monnit Sensor modules*

Some of the common features of these sensor modules are listed in Table I

TABLE I. FEATURES OF WIRELESS SENSORS [7]

Operating frequency	433 MHz
Non-line-of-sight device range	250-300 ft.
Operating temperature	-20° to 60°C (-4° to 140°F)
User defined thresholds for alerts and notifications.	
Battery	1 x CR2032 replaceable coin battery.
Battery life	Depends on the active period of operation of a sensor.
Current consumption	0.7 µA (sleep mode) 2 mA (radio idle/off mode) 2 mA (measurement mode) 25 mA (radio RX mode) 35 mA (radio Tx mode)

B. *Monnit Hub/Gateway*

The MonnitLink™ Ethernet gateway allows the wireless sensors to communicate with the Online Wireless Sensor Monitoring and Notification System without the need for a computer. As shown in figure 1, the sensor nodes send the event logs to the Monnit Hub which in turn communicates with the iMonnit server. Some of the other key features are listed in Table II.

TABLE II. FEATURES OF THE WIRELESS GATEWAY [8]

Operating frequency	433 MHz ISM band
IEEE standard	802.3
Protocol supported	UDP, DHCP, TCP
Power supply	5.5 V AC adapter or power over Ethernet adapter
On-board memory capacity	up to 16,000 messages

C. *iMonnit server*

The iMonnit Server is the locally hosted enterprise software which helps to maintain the sensor data. Monnit Enterprise is available for large organizations with specific data/usage requirements. By using the Enterprise version, we are able to host and maintain our own sensor data, enabling the data about the participant's activities to be maintained on-site, which helps reduce privacy risks.

Using a web-based application, we can modify the sensor configuration to meet the specific requirement. Figure 2 shows the online sensor configuration page of the water flow sensor that is used to detect flow of water in the kitchen. The sensor can be programmed to send data after a specific time interval, called the "heartbeat" of the sensor. Besides the heartbeat, it is possible to set the time to re-arm and the aware-state Heartbeat, among others. [9]

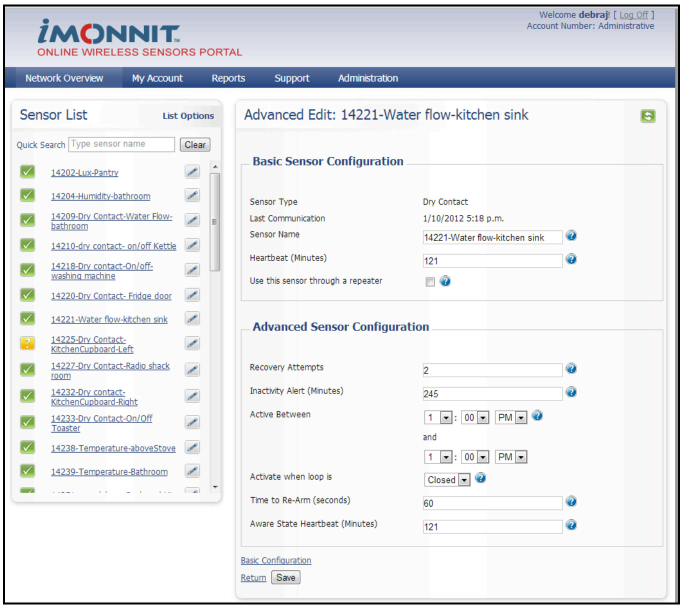

Figure 2. Online sensor configuration

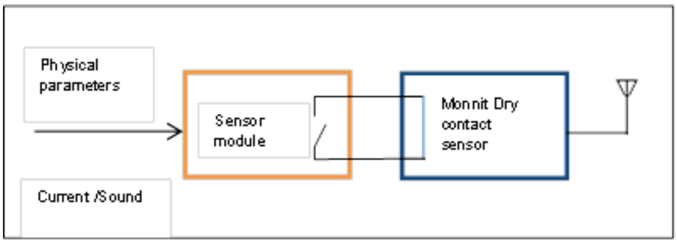

Figure 3. Block diagram of sensor module integrated with Monnit sensors Online sensor configuration

D. Proprietary Mains current detection and water flow sensors

Figure 3 shows the general block diagram of the propriety sensor modules that have been integrated with the Monnit sensors. Massey University, School of Engineering and Advance Technology (SEAT) have developed the mains current sensor and the water flow sensor.

Mains current sensor module:

This sensor is connected to the electrical appliances in such a way that whenever it is switched on, the current is sensed and it closes the relay switch. The relay switch is connected to the dry contact Monnit sensor that sends the signal to the Monnit Hub.

The block diagram of this sensor module is shown in figure 4. An LED is also used to indicate that the electric appliance is currently running. The action of the relay is coupled to the dry contact wireless sensor from Monnit. The dry contact sensor then communicates with the hub indicating that the internal loop is closed

Water Flow Sensor Module:

The monitoring of water use is problematic as the sensors are being retrofitted into the subject's home, and the desire to have as little impact as possible precludes the use of trailing wires above the sink that would be needed by a conductivity sensor, or the use of an impeller sensor as this would require modifications to the plumbing. The solution finally arrived at was the use of an acoustic water-flow sensor. The turbulence produced when water flows through a constriction (such as a partially open tap) can produce sufficient noise for it to be used as a proxy for water-flow. Care has to be taken to attach the microphone as close to the tap as possible.

Two measures were taken to ensure that kitchen noises do not trigger a water-flow indication. Firstly, a high-pass filter excludes frequencies below 10 kHz. This effectively removes voices and most music. Secondly, the noise has to be present without interruption for at least two seconds. Almost all uses of a tap will satisfy this condition and a shower too, whereas voices, the banging of pots on the kitchen bench and other noise will not. They will be above the detection threshold, but will drop below it within the two second limit, and therefore will not pass the time threshold, and therefore are effectively ignored. This method of water-flow detection is not ideal, but it does work and satisfies the "minimal impact" requirement. The basic circuit block diagram of the water flow sensor module is shown in figure 5.

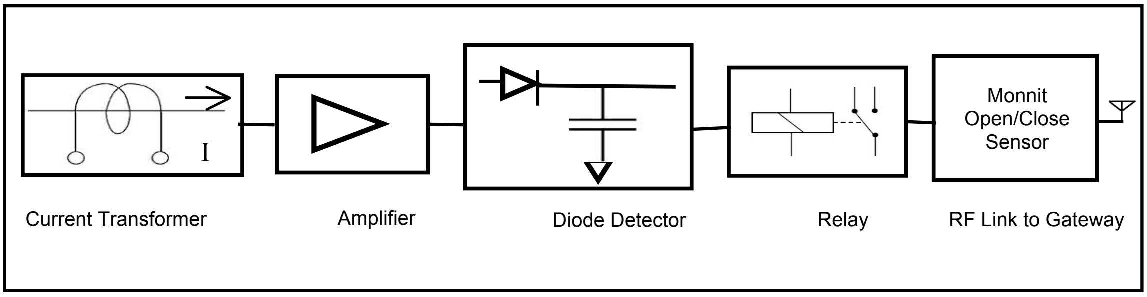

Figure 4. Block diagram of the Mains Sense Module [10]

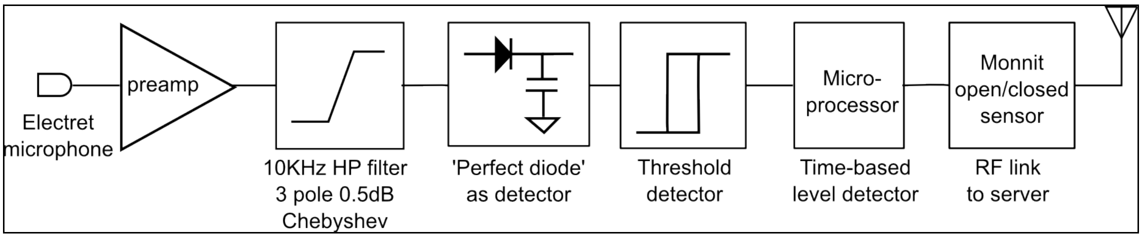

Figure 5. Block diagram of the water flow sensor module

III. Deployment Plan and Execution

The currently installed set of sensors is listed in Table III.

TABLE III. SENSOR LIST AT SUBJECTS'S HOUSE

Sensor type	***Action***	***Location***
Lux	Light detection	Pantry
Humidity	Humidity	Bathroom
Dry contact	Water flow	Bathroom basin
Dry contact	On/Off	Kettle
Dry contact	On/Off	Washing machine
Dry contact	Open/Close	Fridge door
Dry contact	Water flow	Kitchen basin
Dry contact	Open/Close	Kitchen Cupboard-Left
Dry contact	On/Off	Radio shack
Dry contact	Open/Close	Kitchen Cupboard-right
Dry contact	On/Off	Toaster
Temperature	Temperature	Oven
Temperature	Temperature	Bathroom
Open/Close	Open/Close	Cupboard upper left
Open/Close	Open/Close	Cupboard upper right
LUX	Light detection	Back door
PIR	Motion	Dining
PIR	Motion	Toilet
PIR	Motion	Kitchen
PIR	Motion	Front bedroom
PIR	Motion	Hallway
PIR	Motion	Radio shack room
PIR	Motion	Bathroom
PIR	Motion	Subject's room
PIR	Motion	Lounge

The network setup has the primary objective to capture the events that include:

- the presence of the subject in a room
- the use of electrical appliances, such as the toaster, microwave oven, washing machine etc.
- the opening and closing of cupboard and fridge doors
- the use of water in the basins and shower

A. *Installation and monitoring issues*

The output of all the sensors must be able to give a comprehensive picture of the subject's activity through the whole day and night. For example, the motion sensors that are installed at the subject's bedroom, bathroom, toilet, kitchen, dining space and lounge will trigger an event when the subject is in the room. The dry contact sensors that are connected to the toaster, kettle or radio shack equipment should be able to detect the mains current when the connected appliance is in use.

Figure 6 shows the screenshot of the web-based online wireless sensors portal provided by Monnit. It shows the list of sensors that are in operation and the individual sensor log when a particular sensor is selected.

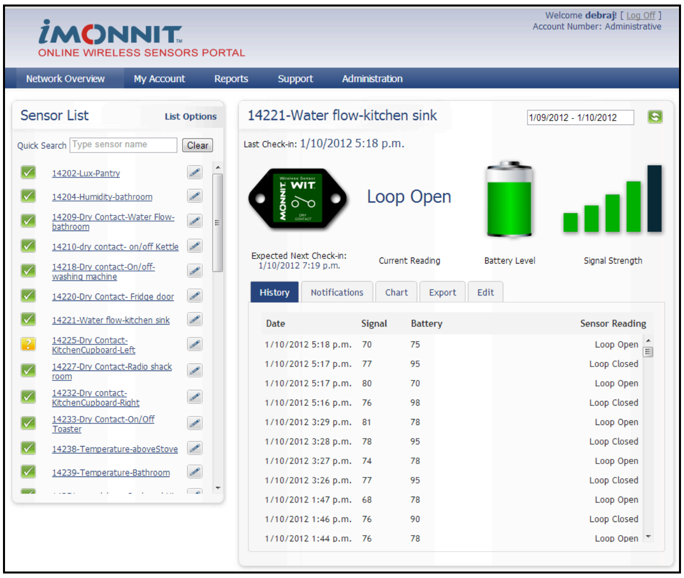

Figure 6. The log of events as reported by a sensor

B. *Accuracy of collected data*

Unlike other research projects, obtrusive sensors such as cameras and microphones have not been used. The system completely relies on unobtrusive sensors for data. Therefore, it is imperative that all the activities are captured correctly before they are forwarded to the next level of abstraction. One way to verify the accuracy of collected data empirically is to find the correlation between the time stamps of activities that have been logged.

For example, when the subject wakes up in the morning and gets of out of his bed to go to the bathroom, the first sensor to log this activity should be the motion sensor of the bedroom. As the subject goes to the bathroom, the motion sensor in the hallway will detect the motion. In the bathroom, the water flow sensor will detect if the basin tap is turned on. To support this sensor, the motion sensor in the bathroom will also detect the presence of the subject.

Similarly, there are other "chains of sensor data time stamps" that helps to empirically verify the accuracy of the data. By accuracy of data, it is meant that the sensors provide exhaustive, repetitive and meaningful data that helps the machine learning approach to work out a model that meets the end objectives.

C. Sensor deployment layout

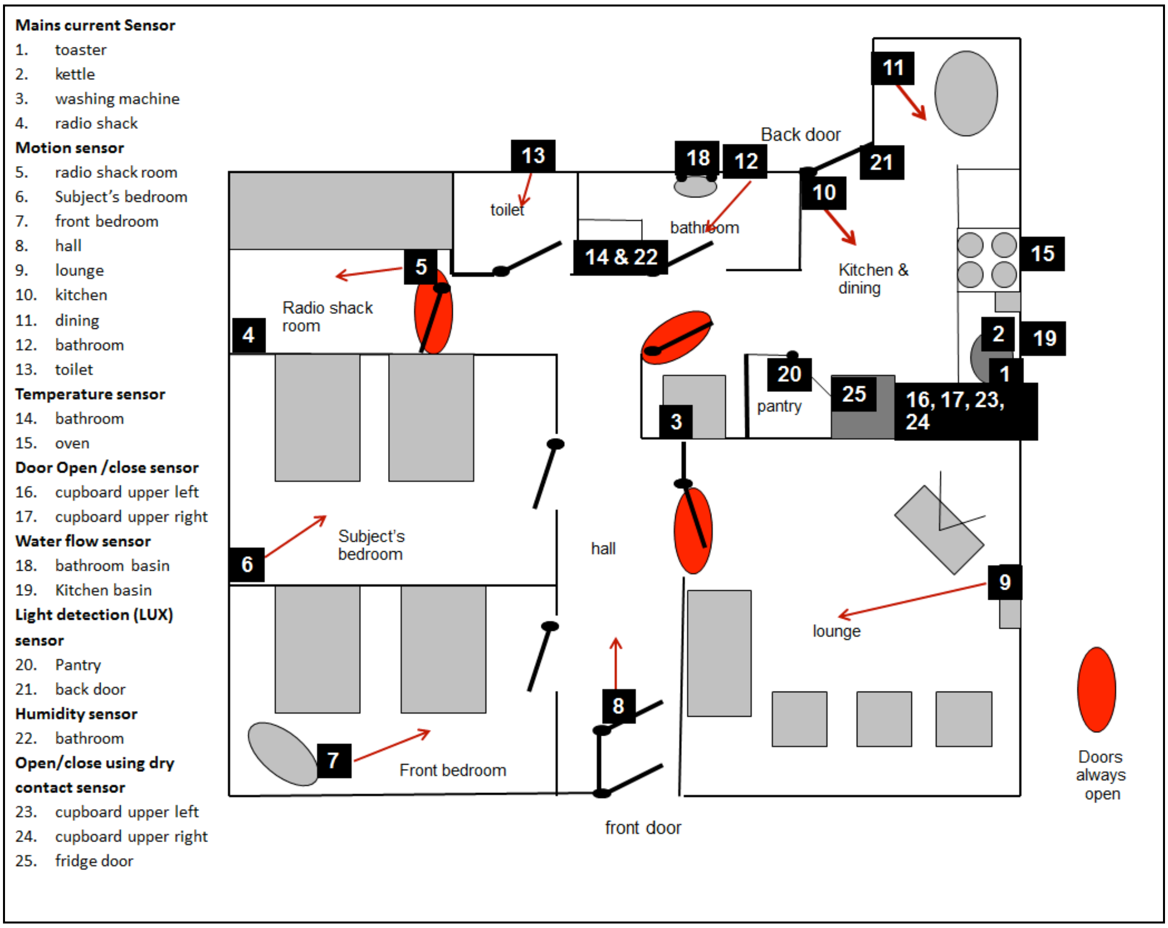

Figure 7. Sensor deployment layout

Figure 7 shows the present deployment status of the sensors in the subject's house. The numbers correspond to the sensor list that is presented on the left side of the figure.

IV. DATA VISUALIZATION TOOL

A data visualization tool has been developed to visualize the sensor data collected from the subject's house. Data is extracted from the iMonnit server and sent to the visualization software. As seen from figure 8, this tool helps to capture the time and duration of activities that the sensors have logged over a whole day. It can be scaled to depict data with a resolution of months and years.

V. DISCUSSION

Commercially available wireless sensors, which are primarily meant for industrial applications, have been used in a novel way to monitor the activities of an elderly person in their own home. The sensor parameters can be easily altered using software and appropriately configured for a specific application. While there are a variety of sensors available, there were none for monitoring electrical appliance usage and detection of water flow. These were designed and successfully integrated with the commercially available open/close sensor. The mains current sensor module is shown in figure 9. It has been successfully tested to detect operation of an electrical load as low as 40W.

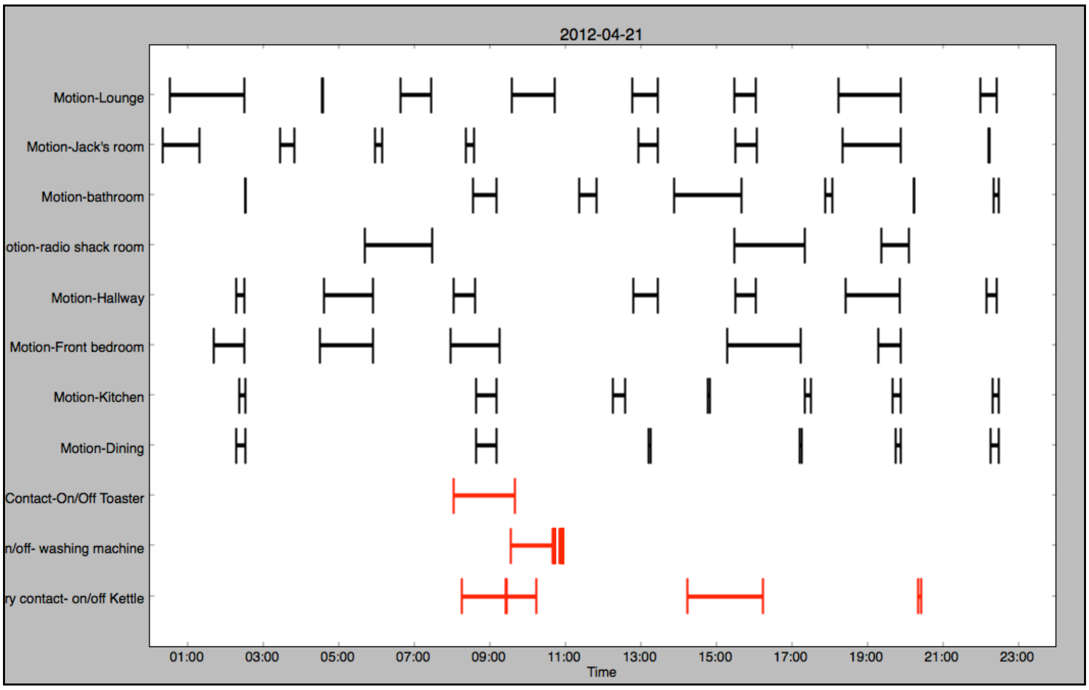

Figure 8. Data visualization tool

The sensors and the hub use proprietary protocols for their wireless communications. Therefore, it is not straight-forward to integrate sensors from other manufacturers. It is a significant challenge to find appropriate placements for the sensors in the house, as it is often not possible to use the most appropriate location for a sensor as this location conflicts with the desire to keep the sensors as discreet as possible, or would result in some property damage (e.g. from mounting holes).

The system has been deployed for about six months and data is being constantly gathered and monitored. Machine learning algorithms are being tested on the gathered data.

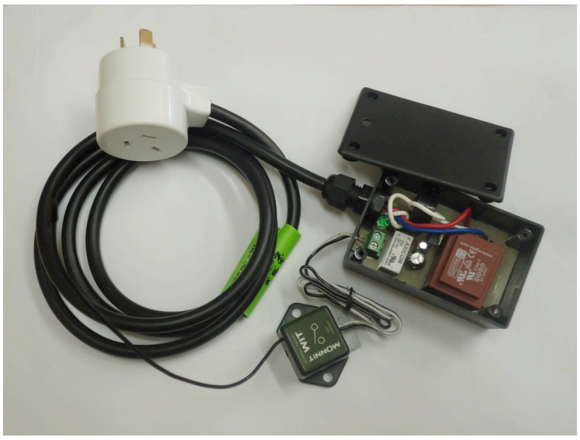

Figure 9. The Mains sensor connected to Monnit Open/Close module

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