Smart Fuse For Appliances

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Abstract

Currently, some home users have the ability to view the power consumed by their household, but nothing to inform them of the power consumed by individual devices. An innovative and creative solution is specified in this proposal, as well as a detailed approach to the resolution of this problem.

/*The introduction contains a background on the problem and some of the already existing solutions as well as what is required in order to satisfy the aims of this project. The proposed project section outlines potential solutions, which will be developed into the final system. The 'Programme of Work' section specifies the key areas of development and displays a Gantt chart to show how my time will be distributed throughout the project. In the 'Resources Required' section I explain any hardware or software I deem are essential to the project and my justifications as to why they are essential. The last section is 'References' and here I provide links to resources I have used to produce this report.*/

1. Introduction

In today's modern society it is extremely important from a social point of view to keep track of your energy consumption and the damage you are ultimately doing to the environment, it's even more important from an economical point of view to save money in today's disastrous economy.

The problem that exists today is that users are able to see the overall power consumed by their household, but not how much energy is consumed by individual devices – this can be compared to a bank account where you can't see individual transactions, it is not very useful.

However, there are products that allow the user to see individual energy consumption, but their limitation is size, and how obtrusive they are into the users' environment. They are also limited in the way they communicate, some devices require manual readings, and others still produce a single figure for the entire household, even though they have readings for each individual device.

To the right, is an existing product that allows individual appliances to be monitored through a device that the user plugs the appliance into, and details are displayed above the socket on a LCD. This approach is limited as you have to manually read figures off of the socket display and you have to buy a socket per appliance – or group appliances together using an adapter.

Another product measures the overall output of a household by attaching a sensor to the mains cable leading into the house. The limitations of this approach are clear. You can only see the consumption of energy as a whole, not individually. However, these devices do allow an accompanying web app and LCD to visualize the energy consumption, which the previous solution lacked.

Finally, the last product has a number of plugs which you can plug appliances into, and they are then fed back to a central hub using the X10 power line protocol. The limitations of this approach are the cost per plug and the central hub price. Also the plugs are very big which is obtrusive in any environment, which is problematic for your average homeowner.

From the three existing products above, there is nothing that is neat, inexpensive and allows the monitoring of individual devices.

The device that should exist, is one that is both discrete in it's implementation, and allows readings per device, with data transmitted to a central storage device, that allows the user to visually breakdown power consumption per device.

2. Generating a System from High Level Requirements

There are a few high level requirements that can be defined at this early stage:

- The device should be able to communicate the energy consumed by an appliance to a central hub.
- The Central Hub should display the data held about each fuse in a graphical format
- The device should communicate readings at a regular interval.
- The device should be unobtrusive in its environment

The first step is to determine where this device is to be embedded. In each electronic appliance, there is only one shared entity, the fuse. Every single appliance has a fuse that breaks when the appliance's circuitry draws too much power. This is an ideal place to insert an embedded system as from this location you can see how much energy the appliance is currently drawing. From now on, this embedded system will be referred to as the Fuse.

The next step is to determine how the Fuse will communicate with the central hub. Wifi and Bluetooth seem like the obvious choices, however, they add bulk to the device, which would reject the requirement for the device to be unobtrusive. Also, Wifi and Bluetooth can be heavily distorted in uncontrolled environments, not unlike the environments in which this device will be deployed, implying that these means of communication aren't suited to this project.

One means of communication that is still heavily utilized today is power line communication. This allows devices to use the infrastructure provided by the power lines of a building as a method of communication. There are existing communication technologies such as X10 and PLC (Power Line Communication) which have defined protocols to allow communication over the power line. Despite having defined protocols, the hardware that is introduced with these technologies is quite bulky as you can see in the third example of existing products. Using these technologies would go against a high level requirement, and would make the end device obtrusive in its environment.

This implies that an existing technology/protocol isn't appropriate for this project, and a new protocol will have to be created that is appropriate for power line communication.

The last a final step concerns the notion of a centralized storage point for all of the data to be sent to, the idea of a Hub. The central hub needs to have some sort of communication with the power line in order to receive information transmitted by the fuse, as well as this the device needs to be capable of storing the received information in a database, that can then subsequently be displayed on a webpage.

3. Derivation of Functional Requirements

From the high level requirements, the components have been generated that will form the end product of this research. Below is a further breakdown of each individual component, and the functional requirements attributed to that component.

3.1 Functional Requirements - The Fuse

- The Fuse should be universally compatible.
- The Fuse should be small enough to fit into a plug.
- The Fuse should be energy efficient and not consume a large amount of electricity.
- The Fuse should be cost effective.
- The Fuse should be scalable to all types of environments.
- The Fuse should sample the energy consumption at a regular interval, and then report the average reading back to the Central Hub.
- The Fuse should be bound to a Central Hub to prevent others from hijacking data.
- Each Fuse should emit a regular pulse that uniquely identifies itself.
- The Fuse should be able to communicate at the same time as other fuses on the power line, collisions should be resolved.
- The Fuse should be able to function as a normal Fuse, and cut off when the circuit draws too much current.
- The Fuse should be easy to install, just like changing a normal fuse.
- The Fuse should have a high tolerance to variability of readings from the appliance.

3.2 Functional Requirements – The Central Hub

- The Central Hub should always be checking for a reading from the power line.
- The Central Hub should be portable and easy to install.
- The Central Hub should store received data in a database.
- The Central Hub should present data in an easy to understand format for the user via a web interface.
- The Central Hub web interface should only be viewable by those authorised to view it.
- The Central Hub should be able to detect and differentiate between each fuse.
- The Central Hub should be cheap and inexpensive.
- The Central Hub should have the ability to be accessed over the internet or through a smartphone application.
- The Central Hub should be able to communicate with other hubs if required, to produce a scalable solution.
- The Central Hub should be device independent.

3.3 Functional Requirements – Communication Protocol

- The Protocol used should be simple and require a small amount of energy.
- The Protocol should automatically detect collisions as they occur and resolve them.
- The Protocol should be able to support a large amount of fuses.
- The Protocol should be able to adapt to large buildings.
- The Protocol should have a distinct format that specifies the packet structure.
- The Protocol should have a simple checksum feature that allows the central hub to determine if all data has been received correctly.
- The Protocol should not exceed the space limitations imposed by the fuse.

4. The Proposed Project

The project is an experiment to test whether an embedded system would work in a place such as a plug and whether power line communication is a viable choice; the end goal is not to have a finished product, but a set of results, which can be used to develop the end product further. The three main areas of focus for this project are to design a fuse that communicates over power line, to gather data sent over the power line using a new protocol created through the conception of this project and to receive those results on a central hub. The final test would be to implement the system in a real environment to see if it promotes energy awareness among the test subjects, and if it is a useful tool to help reduce bill sizes.

4.1 The Fuse

The design of the Fuse should align to the requirements derived earlier in the proposal.

From previous discussions in this proposal, it is implied that the Fuse will consist of a microcontroller and a simple fuse wire that will overheat if too much current is drawn by the appliance. The microcontroller contains software that will drive the sampling of the power usage of the appliance, and the transmission of data over the power line using a brand new protocol.

When developing the fuse, safety is of paramount importance, which means development will need to occur using a low voltage testing harness, ideally 16v.

An ideal sampling rate needs to be determined during development, so that accurate readings are transmitted to the central hub. Also a tolerance will need to be determined during development, so that an offset can be calculated to normalize outliers when sampling the appliance voltage.

Then the issue arises of how to actually sample the appliance. There are two key types of current, Alternating Current (AC) and Direct Current (DC). DC is the ideal situation and requires a simple equation called Ohms Law:

$$\mathrm{P{=}I^2{\times}R} \qquad where\ \ P\ is\ the\ Wattage, I\ is\ the\ current\ and\ R\ is\ the\ resistance.$$

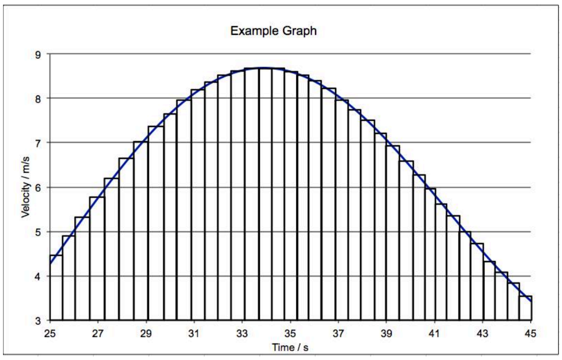
This would be complex to implement, however, AC is far more complex:

$$\mathrm{P_{avg}} = \mathrm{V{\times}I{\times}}\cos\emptyset$$

The formula above requires the constant sampling of a complete sine wave produced in the AC circuit, once a complete cycle has been sampled, the power can be calculated. Both types of current have their own complexities, but to begin with, embarking on the DC type would be ideal, as it is simpler than it's AC equivalent. Once the DC implementation is complete, development of the AC approach will begin.

One important aspect of the Fuse that can't be overlooked is its ability to detect which type of current is flowing and perform subsequent calculations appropriately.

Another element that needs to be investigated is how an AC wave is sampled.



The image to the right shows an example method of determining the area under a curve. Integration is used at various sample points across the waveform, from the values returned by the integral, you can then calculate an approximation of the area underneath the curve. Of course, an AC waveform alternates between positive and negative values, an absolute value would have to be returned for those points sampled in the negative region of the waveform.

4.2 Communication

As determined earlier in this proposal, there are no suitable communication protocols for this project, so there is a need to invent a new protocol.

The protocol will need to align with the requirements specified earlier in the document.

During the development phase, the best approach would be to transmit pulses at a regular interval, and use a wave oscillator to detect differences in the waveform to see if the device transmissions are detectable.

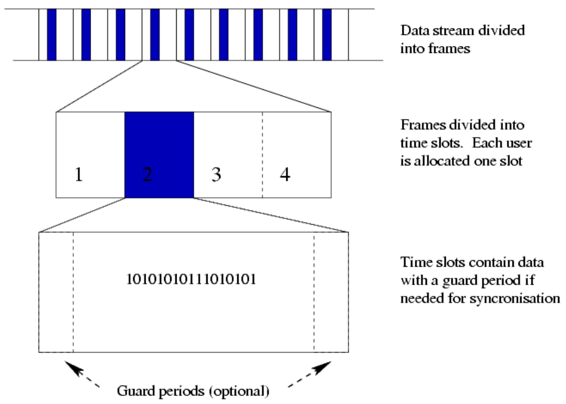
Each fuse will need to be able to be uniquely identified; this can be done at manufacture by assigning each fuse a unique id a similar concept to MAC addressing.

Existing systems work by modulating a carrier signal onto the power line. The power line typically transmits at frequencies between 50Hz and 60Hz, the devices built for detecting transmissions on the power line are aware of this fact and look towards detecting transmissions at much higher frequencies between 100Hz and 200Hz.

It is entirely plausible for a microcontroller to modulate frequencies up to this range; the next task will be to determine how to handle collisions on the power line.

The two methods of collision detection and resolution are Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA).

TDMA divides transmissions over time using slots defined slots assigned by a host. The Fuse system will have unidirectional communications to begin with; so assigning slots to each Fuse is not possible. A possible solution to the problem is to introduce a back off, which prevents each fuse from transmitting for a random amount of time if a collision is detected.



Alternatively, CDMA could be used instead. An analogy for CDMA is a room (channel) where people want to talk to each other simultaneously, if people talk in different languages (codes), you can isolate each language, and translate what they are trying to say. If each Fuse is required to speak a different language, a table of codes could be stored on the microcontroller and depending on the mac address of each fuse, the respective channel code is selected, then subsequently used in its implementation.

The CDMA version implemented would have to be synchronous which would require orthogonal coding in the implementation. Orthogonality in this case is determined by the dot product of two simultaneous signals which must resolve to 0 i.e. they do not interfere with each other. *Maximum number defined by welsh code is 64 orthogonal signals…?*

Packet Definition:

0	1	2								3															
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Type	Status	Checksum								Payload															

The entire packet uses 26 bits

Type - used to indicate what content is contained in the payload whether the reading is an Average (AC) or an Actual reading (DC). Consumes one bit of the packet.

Status – used to indicate if the appliance is currently on or off. 1 for on, 0 for off. Allows the immediate evaluation of a packet, without looking at its payload. Consumes one bit of the packet.

Checksum – used to check if the packet has been corrupted during transmission. Consumes 8 bits of the packet.

Payload – the content of the transmission. Consumes 16 bits of the packet.

4.3 The Central Hub

As discussed in the requirements section, the central hub will require a database to store data received over the power line. In terms of databases there are 2 distinct solutions that present themselves, MySQL and SQLite. MySQL is suitable for large scale and production developments, which is a requirement not matched by the proposed system. On the other hand SQLite is great for testing, prototyping and embedded systems, it's lightweight, simple to deploy, and requires little or no administration – an ideal solution.

The functional requirements state that the central hub to be cheap and inexpensive. For the required level of functionality, a simple inexpensive device would be a Raspberry Pi, which draws relatively low amounts of power, is small and unobtrusive, has the ability to communicate with other devices via mediums such as Bluetooth and Wifi and allows for a large multitude of scripting and programming languages.

Obviously the Central Hub must understand the protocol outlined in 4.2 and be able to interpret data sent over the power line.

4.4 Additional Scope For this Project

Bidirectional communications would add a number of features and benefits to the system. The first immediate benefit it would bring is the ability to communicate with fuse, which would thereby allow some sort of appliance control, turning the appliance on and off for example.

The next benefit that this would bring is the dynamic allocation of unique addresses. This means that no two Fuses will have the same address, and the Fuse would operate in a plug and play fashion. With the present MAC addressing solution, there is still a small chance that two devices could end up on the same system, which would cause errors. Along with this dynamic allocation of addresses, channel codes for CDMA could be allocated at the same time. In essence the Fuse would communicate using TDMA initially, but would then begin to use CDMA once a unique address has been assigned and a channel code received.

One final benefit that bidirectional communication would bring is security. Security could be enforced through the binding of fuses to hubs. Each hub would have its own unique table of channel codes that it can assign, thereby only allowing messages to be understood by hubs with the channel codes assigned to them.

A major addition to the SmartFuse would be a Polymeric Positive Temperature Coefficient (PPTC) device. The PPTC device would act as a fuse, the main benefit being its reusability. PPTC devices match current with resistance as the current is raised, meaning that if a circuit began to draw too much electricity, the PPTC device would match this with resistance, preventing circuit load. Once the huge amount of current is removed, the resistance is reduced to a conductive state once more.

5. Programme of work

6. Resources Required

7. References

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