Home Appliance Energy Monitor

ECE 445 Design Document - Fall 2023

Project # 25

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Introduction

Problem

As a technologically modern world, we have a lot of home appliances that are consistently reliant on a lot of electricity. However, we tend to overuse these devices, thus leading to dangerously high electricity usage. An average of 34% percent of electricity at the household is wasted. This problem would become more apparent to users if they were able to visualize and track their electricity consumption for each home device because many users are unaware of their electricity consumption patterns and do not realize the extent of wastage that occurs.

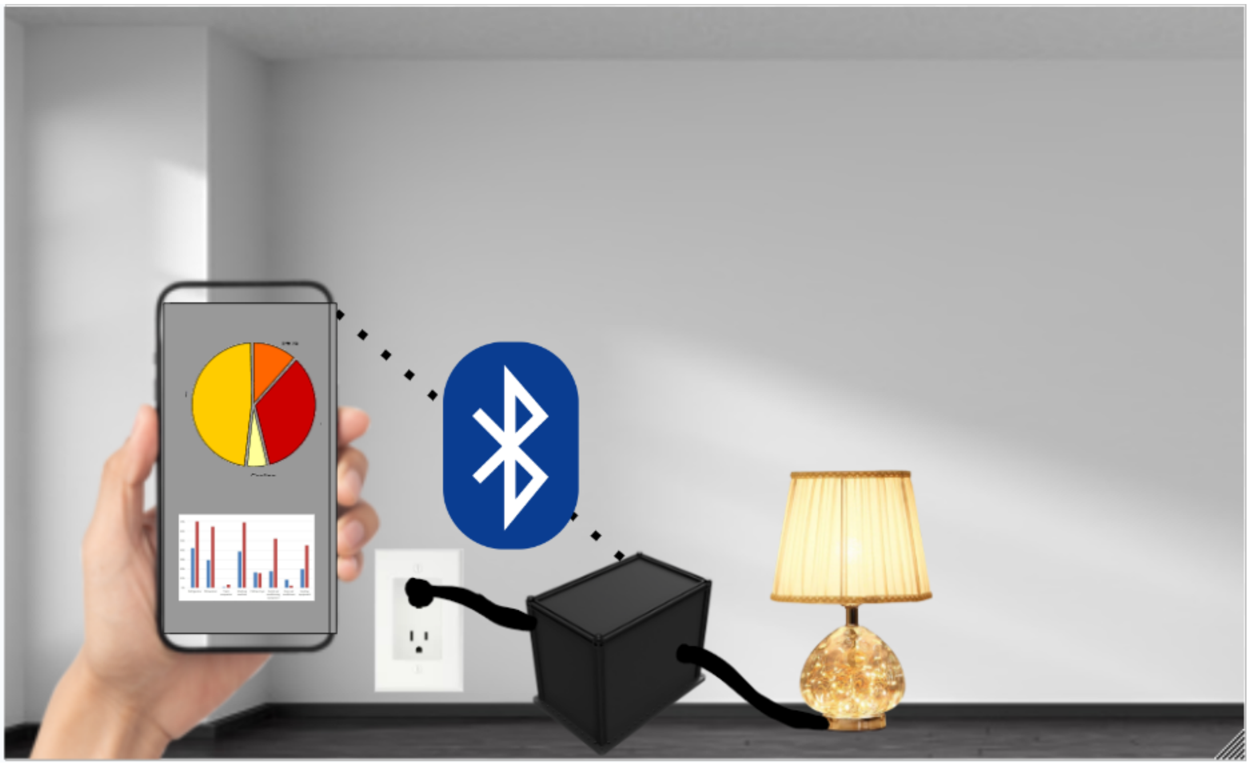
Due to convenience, entertainment, and forgetfulness, the average modern lifestyle does not spend time being more mindful about their electricity consumption. Even though there are quick actions that can be taken to reduce the consumption of electricity, individuals cannot make informed decisions. For example, homeowners may see high utility consumptions but don’t exactly know what appliances are disproportionately contributing to the total electricity consumption amount.

Solution

To address the electricity consumption problem, a viable solution needs to enable better decision-making by users to better manage electricity consumption. The electricity usage of home appliances needs to be tracked to understand how to make adjustments to how individuals consume electricity and understand patterns of usage.

The solution we will be implementing is a Bluetooth-enabled electricity monitor for home appliances. This monitor would track electricity consumption for the connected device over a period of time. There would be a microcontroller to process the values from the sensors and handle communication. An app would be made to display the results and send notifications to users if a certain device is consuming dangerously high amounts of power.

Visual Aid



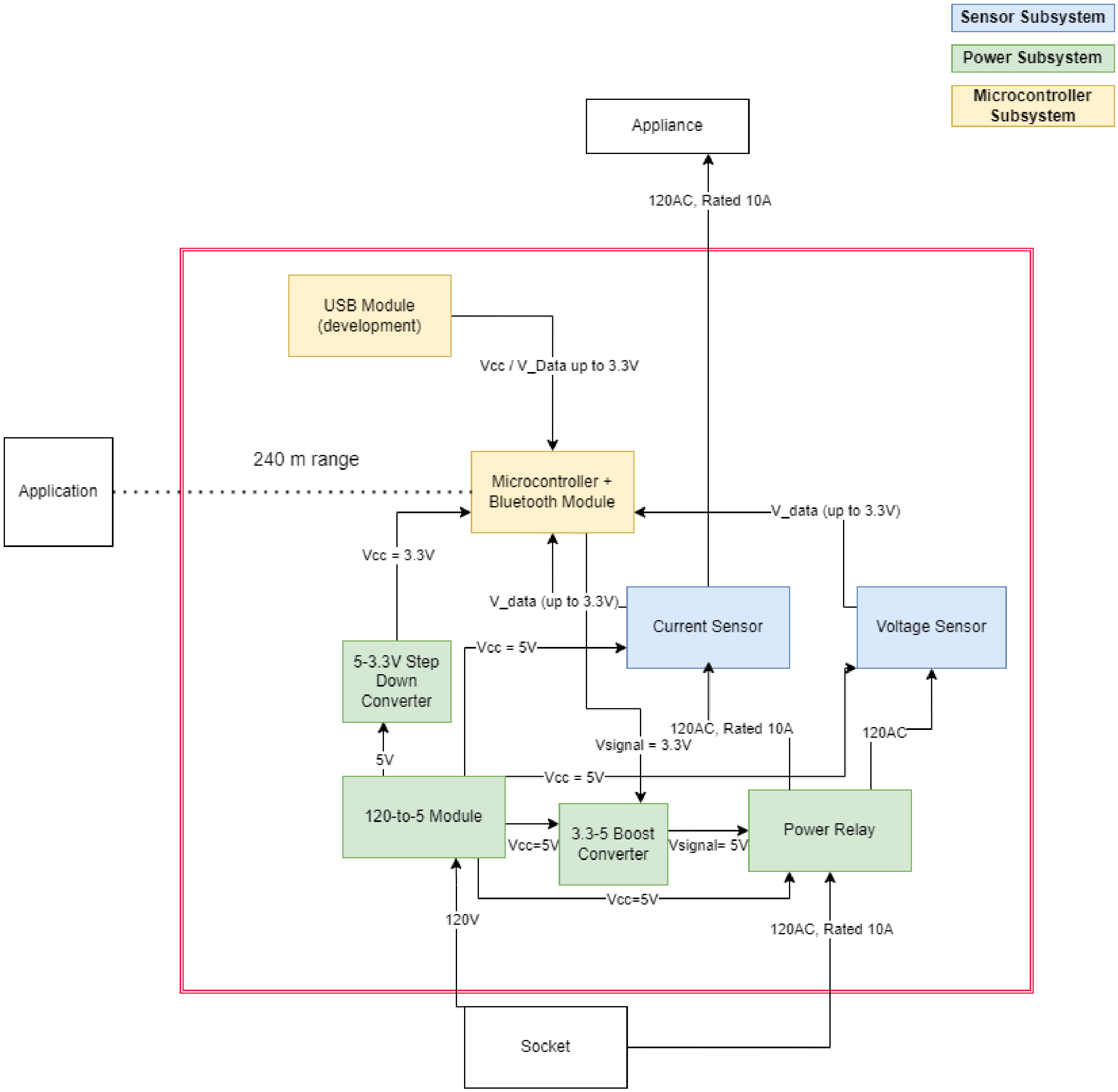
High-level requirements list

- A durable physical device that can be plugged into wall outlets in the US (120VAC, RMS) and accurately measure and transmit power consumption to an application.
- The application is able to fetch data wirelessly that is visually appealing and easy to understand for the customer. This reach should be up to 100 meters as this is the normal bluetooth range.
- We aim for an accuracy of +- 5%. The standard we will be referencing is IEEE-Standard 1459-2010. This standard defines terms, concepts, and test methods for the measurement of electric power quantities.

Design

Block Diagram

A general block diagram of the design of your solution. Each block should be as modular as possible and represent a subsystem of your design. In other words, they can be implemented independently and re-assembled later. The block diagram should be accompanied by a brief (1 paragraph) description of the critical subsystems and what they do.



Our device is completely enclosed in the red box in the above figure. As shown in the block diagram, the device will be connected to the socket, the application, and the appliance. The current drawn from the device is measured and sent to the microcontroller and transmitted via the bluetooth module to the backend of our application. We have divided the block diagram into three subsystems, as color coded in the block diagram: We have a sensor subsystem, a power subsystem and a microcontroller subsystem.

Subsystem Overview:

The first subsystem we have on our board is the **Microcontroller Subsystem**. This subsystem will be responsible for handling the turning on and off of the power relay, calculating the power value, and for relaying the power consumption information to our app via Bluetooth. The specific microcontroller we will be using for this subsystem is the ESP32. The microcontroller will be interacting with the power subsystem to receive 3.3 V to activate the enable pin. It will also interact with the power relay by telling the power relay to turn the power supply off if energy exceeds the user designated maximum power. The microcontroller will be interacting with the sensor subsystem by reading in voltage and current values periodically to calculate how much energy is being consumed by the connected appliance.

The second subsystem we have on our board is the **Power Subsystem**. This subsystem is responsible for powering the components on the board as well as controlling power supply to the appliance. The components in this subsystem are transformers and a power relay. There will be one 120 to 5 V transformer (LRS-35-5) to convert the voltage coming in from the socket to something that is apt for powering our sensors. There will be a 5 to 3.3 V (AMS1117-3.3V) transformer as well as a 3.3 to 5 V (Comidox 3.3 to 5 V transformer) transformer to control power going in and out of our microcontroller. Lastly, there is a power relay (Omron g5le-14 5vdc) that interacts with our microcontroller to determine if the connected appliance can continue to draw supply voltage or not.

The last subsystem we have on our board is the **Sensors Subsystem**. This subsystem is responsible for measuring the voltage and current draw of the connected components. A voltage sensor (ZMPT101B) and a current sensor(ACS712ELCTR-20A-T) will be present in this subsystem. These sensors will be connected to the microcontroller subsystem as the microcontroller will be responsible for processing the values these sensors will be providing. These sensors will be receiving 5V of power from the 120 to 5 V transformer in the power subsystem.

Subsystem Requirements:

Microcontroller Subsystem:

Requirement	Verification
• We want to be able to read in values every 5 seconds.	• This requirement can be confirmed via our front end app. If a new point appears on the energy graph (graph on the front end app) every 5 seconds, then our microcontroller is reading values according to our set period.
• The second requirement for this subsystem is the ability to control the power relay. If the power consumption exceeds the set safe limit, then the microcontroller should control the power relay to not let any voltage supply through.	• We can test this requirement by using a voltmeter to check the voltage going through the power relay.
• The last requirement is the ability for this microcontroller to alert users if power consumption is too high.	• We will have logic set in our firmware to determine if power consumption of the appliance is too high. To test this, the microcontroller should send users an alert on the user front end.If the alert is received appropriately, then our microcontroller subsystem has passed this requirement.

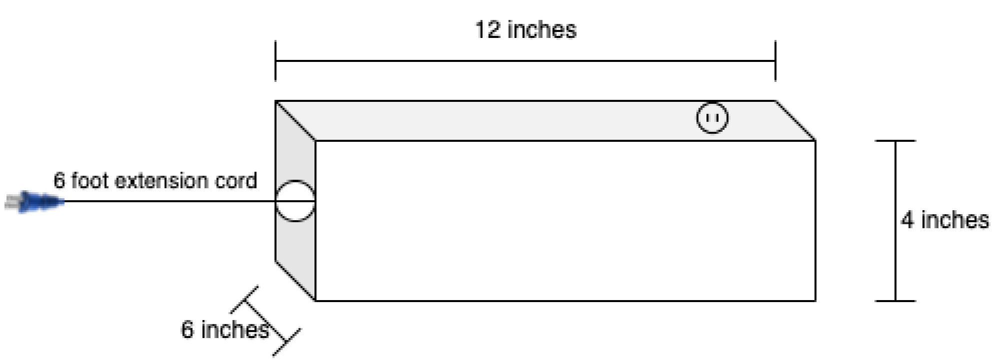
Power Relay

Requirement	Verification
• The requirement for the 120 V to 5 V transformer is to properly convert 120 Volts to 5 Volts and then power sensors with the newly converted 5 volts/ • The requirement for the 5 to 3.3 V transformer is to properly convert 5 volts to 3.3 volts and then power the microcontroller accordingly. The requirement for the 3.3 to 5 V transformer is to properly convert the 3.3 Volt output from the microcontroller to 5 volts.	• We can confirm all these values by using a voltmeter to test voltage values at different parts of our circuit.
• The power relay's requirement is to allow the voltage supply value through if the microcontroller allows such to happen and to not allow any voltage supply through if the microcontroller indicates that to happen.	• We can test this requirement through again using a voltmeter to test voltage values going through the power relay.

Sensors:

Requirement	Verification
• The requirements for the current and voltage sensor are to just send the measured voltage and current values properly to the microcontroller.	• We can confirm this by seeing that whatever value is measured by the sensor is received by the microcontroller. One thing to keep in mind is the communication protocol between the sensors and microcontroller. To properly test this requirement, we would have to follow the procedure of the communication protocol between the microcontroller and the sensors.

Physical Design



Our physician design consists of a pcb board that will be in an enclosure above. The dimensions for the enclosure is available in the above image. This enclosure will be made of plastic as this will allow our bluetooth signal to pass through. An extension cord will go into the box as seen on the left of the diagram. This extension cord will be plugged into our wall socket that provides the electricity. We will also be having a socket on our enclosure that will allow our appliance to plug into our monitor.

Tolerance Analysis

Our objective with tolerance analysis is to determine the worst-case tolerance of the power measurements based on the component tolerances to ensure that the overall error for power measurement does not exceed ±5%.

For the purposes of this document, we will demonstrate a simplified version of tolerance analysis. We will use 3 components' tolerances to calculate the worst case tolerance for measurement.

a. Voltage Sensor (ZMPT101B): ±X%

b. Current Sensor (ACS712ELCTR-20A-T): ±Y%

c. ADCwithin the microcontroller: ±Z%

For a worst-case scenario analysis, we will consider all components to be at their maximum tolerance at the same time.

To calculate the error to measure voltage and current, you can use the following formulas:

$E\_voltage = X + Z$

$E\_current = Y + Z$

And to measure the real power consumption, you use the formula: $P = I * V$. Therefore to measure E_power, it would be $E\_power = (X+Z) + (Y+Z)$. For our project, E_power must be under 5%.

This methodology can be expanded to fully consider all components in our schematic to provide a better understanding of the tolerance. This sort of tolerance analysis can also be used to ensure that the ratings of individual components are not exceeded, which is necessary to ensure the safety of our design.

Cost and Schedule

Cost Analysis

Include a cost analysis of the project by following the outline below. Include a list of any non-standard parts, lab equipment, shop services, etc., which will be needed with an estimated cost for each.

Labor:

Guneet Sachdeva: ($52/hour) x 2.5 x 400 = $52,000

Om Patel: ($52/hour) x 2.5 x 400 = $52,000

Ravi Thakkar: ($52/hour) x 2.5 x 400 = $52,000

Parts:
Include a table listing all parts (description, manufacturer, part #, quantity and cost) and quoted machine shop labor hours that will be needed to complete the project.

Description	Manufacturer	Part #	Quantity	Cost
Microcontroller	Espressif	ESP32-S3-WROOM	1	$3.20
Current Sensor	Allegro Microsystems	ACS712ELCTR-20A-T	1	$3.79
Voltage Sensor	Noyito Technologies	ZMPT101B	1	$6.99
Power Relay	Omron Electronics	Omron g5le-14 5vdc	1	$1.52
Extension Cord	N/A	N/A	1	$8
DC-to-DC Step Down Converter	Advanced Monolithic Systems	AMS1117	2	$4.33
120-to-5 AC-DC Converter	Mean Well USA	RAC10-05SK/277	1	$14.12
Connector	ECEB	277-1263-ND	3	$5.75
3.3 to 5 V	Comidex	B07L76KLRY	1	$5.12
Total Quantity/Cost			**13**	**$61.87**

Sum of Costs
Each Member Salary = $52,000
Number of Members = 3

Total Member Salary = $156,000
Total Parts = $61.87
Spare Parts = $61.87
Total = $156,123.74

Schedule

Tasks	Start Date	Goal Date	Individual Contributions	Completed?
Finish Design Doc	9/24	9/28	Ravi, Guneet, Om	Y
Finalize Parts to be used	9/28	9/30	Ravi, Guneet, Om	Y
PCB first Draft	9/28	10/1	Om	Y
Review PCB/Container design with Machine Shop	10/4	10/8	Ravi, Om	Y
Get first round PCB order in	10/6	10/10	Om	Y
Last machine shop revisions	10/9	10/13	Ravi	~
Team Evaluation	10/10	10/11	Ravi, Guneet, Om	Y
Update PCB design	10/11	10/15	Om, Guneet	Y
Review PCB design with Machine shop/TA	10/14	10/17	Om, Guneet	~
Begin Firmware	10/17	10/23	Ravi, Guneet	
Solder/Test PCB	10/18	10/22	Om, Guneet, Ravi	
Review PCB	10/19	10/23	Guneet, Om	

design with Machine shop/TA				
Individual Progress Reports	10/21	10/25	Ravi, Guneet, Om	~
FINAL PCB ORDER	10/23	10/24	Om, Guneet	
Solder/Testing	10/24	…	Om, Guneet	
Firmware	10/24	…	Ravi, Guneet	
Create App	10/24	…	Ravi	~
Prepare draft demo	11/9	11/12	Ravi, Guneet, Om	
Mock Demo	11/13	11/17	Ravi, Guneet, Om	
Team Contract Fulfillment	11/15	11/17	Ravi, Guneet, Om	
Prepare Final Demo	11/15	11/29	Ravi, Guneet, Om	
Final Paper	11/17	12/6	Ravi, Guneet, Om	
Final Demo	11/27	11/29	Ravi, Guneet, Om	
Prepare mock presentation	11/28	11/30	Ravi, Guneet, Om	
Mock Presentation	11/30	12/1	Ravi, Guneet, Om	
Prepare Final presentation	11/29	12/3	Ravi, Guneet, Om	
Final Presentation	12/4	12/6	Ravi, Guneet, Om	
Lab Checkout	…	12/7	Ravi, Guneet, Om	

Lab Notebook due	…	12.7	Ravi, Guneet, Om	

Discussion of Ethics and Safety:

Ethical and Safety Concerns

- Safety Issue: Dealing with high voltage will require us to take extra precautions during testing and building of our appliance
  - Ensure that all team members are aware of the dangers of high voltage and have undergone proper training in electrical safety
  - Work on circuit when not plugged in
  - Sources are grounded when dealing with live wires
  - Have someone with you during lab work
  - Make sure there everyone is using proper protective equipment including gloves and ESD equipment and goggles
- Safety Issue: Handling different tools in the lab
  - Never be in the lab alone
  - Ensure everyone is trained on the proper usage of each tool, including understanding its limitations.
  - Properly store: Tools should be stored safely and organized to avoid potential hazards
- Electrical Safety- Design:
  - It is imperative that we are evaluating the device, constituent components, and the connections between the components and the socket/appliance. We would need to carefully read the components' ratings and take notes of the characteristics to make sure every component is compatible with each other.
  - The device should be designed with proper insulation, grounded, and compliant with electrical safety standards. Safety warnings and instructions should be clearly provided to the users.
- Wireless Communication/Bluetooth Safety:
  - We need to make sure that our components are compliant with regulations for wireless communication
- Application Safety
  - We need to make sure that any sort of data being used by the application is secure and protected.

Safety Manual

- High Voltage
    - General Precautions
        - Always assume you are dealing with high voltage
        - Follow the buddy system and make sure someone is with you
        - Keep workstation clean and organized
        - Comply with local electrical guidelines
        - Be ready for emergencies by having medical assistance of way of contacting for assistance nearby
    - Protective Equipment
        - Wear insulating shoes if dealing with live voltage
        - Wear insulating gloves
        - Wear safety goggle
    - Working on Project
        - Always make sure voltage is disconnected before working on device
        - Use insulated tools and gear
        - Have plan ready for emergencies
    - Emergency Protocols
        - Electrical Shock
            - Do not touch electrocuted area
            - Disconnect Power
            - Call for supervisor or medical assistance
        - Fire
            - Ensure own safety
            - Use Class C fire extinguisher for electrical fires
            - If caught on fire: Stop, Drop, and Roll

Citations

Any material obtained from websites, books, journal articles, or other sources not originally generated by the project team must be appropriately attributed with properly cited sources in a standardized style such as IEEE, ACM, APA, or MLA.

"IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions," in IEEE Std 1459-2010 (Revision of IEEE Std 1459-2000) , vol., no., pp.1-50, 19 March 2010, doi: 10.1109/IEEESTD.2010.5439063.

Estimating appliance and Home Electronic Energy use. Energy.gov. (n.d.). https://www.energy.gov/energysaver/estimating-appliance-and-home-electronic-energy-use

M. Mahith, D. S. B. Kumar, K. C. Prajwal and M. Dakshayini, "Bluetooth Home Automation," 2018 Second International Conference on Green Computing and Internet of Things (ICGCIoT), Bangalore, India, 2018, pp. 603-607, doi: 10.1109/ICGCIoT.2018.8753094.