KOÇ UNIVERSITY

College of Engineering

ELEC 491 – Electrical Engineering Design Project

Final Report

ARDUINO-BASED ENERGY MONITORING WITH ELECTRICITY THEFT ALERT

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Abstract

The energy crisis is one of the most important problems facing the world these days. One of the causes of the energy crisis is the waste of energy. If the user can monitor the amount of energy consumed, the energy waste can be reduced. Moreover, while monitoring energy consumption, the user can be alerted in times of energy theft. This project is an Arduino-based energy monitoring system that can detect energy theft. The current sensors connected to the Arduino send the total and user's energy consumption value to the Arduino Uno. The Arduino Uno sends these values to the user's Android smartphone via the Wi-Fi module. In the case of safe mode, the total and periodic energy consumption value is shown on the user's application. In case of energy theft, theft will be detected by calculating the difference between total energy consumption and the user's energy consumption, and a warning will appear on the screen. In addition, users can check the total energy consumption and theft warning on the LCD screen more instantly.

Our goal at the end is detecting energy consumed on an electrical system instantaneously by the client and sending the information through Wi-Fi module to client's mobile application for making the client aware of their energy usage while also detecting electric theft using a Arduino Uno as a detector of electric passage on wires which lead to energy consuming parts of the circuit and sending warning to the mobile application in case of energy usage of the thief.

In order to achieve the goal, our project consists of two main parts: hardware and software. The hardware part consists of a circuit, and is a mini demo of the user using electricity and a thief stealing electricity from them. The software part consists of an application that receives data from the circuit via Wi-Fi.

The ultimate success in meeting these goals is to be able to stop electricity theft and encourage the user to use less electricity.

1. Introduction

Energy crisis is a global issue in the current world. People are more than willing to monitor their energy usage and take the necessary measures to decrease their energy consumption in order to support their environment, governments and finances. Although there are technologies developed for energy monitoring for a household, the biggest issue about electricity usage faces a gap: effective electricity theft detection.

Our project goal is to monitor the energy consumption and detect electricity theft in an electrical system. What we aimed for was creating a miniature city electricity distribution system.In this system we had a client branch simulating user's house, a theft branch simulating illegal electricity usage done by a theft in a city, and a main branch simulating the electricity distribution company's main electricity line. We compare the data collected from the main branch and client branch and detect theft if the compared values differ above the decided threshold. Our goal can be achieved by notifying the user. We do so by using a mobile application. With the application the user gets notification, can check how much energy is being lost and how much energy is being used in total so that the necessary measures can be taken. This way both users and distribution companies can be informed.

Particularly recent events have pushed many nations to the brink of an energy crisis. People are more conscious of the energy use they generate. 20% of the nation's total energy usage in the USA is consumed by households [1]. Therefore, controlling residential energy use is the least consumers can do to assist governments during an energy crisis. In an economic sense, controlling one's own energy use is advantageous to both the individual and the government. Consumer bills across Europe have increased in price by more than 40% since last year, according to the European Commission's Quarterly Report [2]. Determining the amount of energy used is therefore essential to save the environment and excessive bill costs.

People will save money as a result of being conscious of their consumption, but there are other reasons for people to monitor their energy use beyond reducing their own consumption. Theft of electricity affects people everywhere. The global loss from electricity theft, or "non-technical losses," is $96 billion annually [3]. There are three common ways to steal electricity: directly tapping into the lines and using the power, tampering with energy metres, which are quite antiquated in today's digital age, and disconnecting the neutral line and short-circuiting the phase coil of the current transformer [4]. Most often, current sensors are mounted on the lines to detect electricity theft.

Currently, one method of determining a household's energy usage is to look at the power bill at the end of the month; however, this may result in irrational electricity use throughout the duration of the entire month. The user end will benefit more from a quicker method of determining energy usage. Governments and individuals alike may benefit greatly from the development of a device that can detect both energy usage and electricity theft. The creation of a mobile application for energy usage and theft detection is our goal for this reason.

We wish to create an original mobile application, but there are already solutions for knowing how much energy is being consumed right now. Seven instances of how energy use can be tracked will be looked at: smart plugs, whole home electricity monitoring tool, monitors with appliance recognition features, idle load electricity detection, energy monitors connected with mobile applications, energy usage cost tracking, using timers to manage consumption [5].

Small individual appliances like blenders, irons, and other similar items can be plugged into a smart socket, which will then turn on and display the amount of electricity used. Whole-home energy monitors provide a comprehensive picture of how much electricity is used in homes; by attaching their sensors to the electrical panel, they can track the energy use of all the equipment in a home. Instead of tracking the total amount of electricity consumed by the entire house, monitors with appliance identification capabilities are more powerful whole-home monitors with an integrated appliance recognition feature for managing energy consumption of each specific item in detail. Some monitors are able to identify vampire loads, often referred to as idle load electricity, which is electricity used by appliances that are in standby or sleep mode and can account for up to 25% of the overall electricity bill [6]. Connecting energy monitors to mobile applications is a simpler and more user-friendly method that can warn consumers about their excessive power usage, assist in setting energy consumption goals, provide advice on how to save energy, remotely turn off an appliance, and save time over manually checking the monitor. With energy usage cost tracking the client's home is monitored by the real-time cost tracking feature, which tracks how much energy is used and tracks variations in expenses over the course of the day or when a device is turned on or off. One can limit their energy usage over time by using timers to manage consumption. This involves turning off a device using timer-based software.

There is no gadget that is frequently employed when electricity is stolen. There are some published IoT, GSM, and machine learning or deep learning-based systems. Artificial intelligence and machine learning require large amounts of data, their management, and turn out to be extremely expensive or flawed for many nations. The Challenge of Non-Technical Loss Detection Using Artificial Intelligence: A Survey by Patrick Glauner et al. examines and publishes the open challenges of identifying non-technical electric usage. There are no real-time implementations of GSM-based solutions; they are on the level of academic projects. Some methods compare the current values of the main energy distributor and power users, while others use the output from the electric meter. Changes to the electric meter are one of the most common stealing methods. India, which has the highest rate of electricity theft, aims to completely digitise its infrastructure [7].

In our project, we will use current sensors in conjunction with a smartphone application to detect theft. There is nothing like this in the area, so it will be novel. Although there are uses for measuring energy consumption rates, being aware of power theft is more advantageous than striving to use less electricity because it indicates that a whole other home is consuming the energy. The timeliness of the project can stretch as long as electricity is used in households and its transmission done by wires.

2. System Design

Our project consists of two main parts, hardware, and software. In the hardware part, we prepared an electrical circuit and made a mini demo of electricity theft in daily life. Electric theft means that a thief uses the current of the client branch without the knowledge of the client. In the software part, we prepared an application that can run on an android phone.

2.1 Hardware Design

Our circuit consists of three main branches: main, theft, and client branches. The main branch represents the current coming from the main switchboard. For example, in a house example, it shows the current coming from the main switchboard to the house. Our circuit works with alternating current and our system energy source is the socket, so the main branch is powered by 220 V energy. The main branch has a magnetic current sensor to measure the current from the mainstream. The theft branch represents the energy consumption of the person who stole the electricity. The theft branch is connected in parallel with the client branch. It consists of a lamp, a socket, and a switch. The lamp acts as an indicator that the thief has stolen the electricity. The purpose of the socket is to draw a varying current from the main branch. When the switch is open, the thief is using the client's current. When the switch is closed, there is no theft. The client branch represents electricity usage from the mainstream. It consists of a lamp, a socket, and a magnetic current sensor. The lamp acts as an indicator that the client is using electricity coming from the mainstream. The purpose of the socket is to draw a different current from the main branch. Using a socket in the client branch has the same purpose as for the theft branch. The client branch also has a magnetic current sensor to measure the current in that branch. Our circuit also has two Arduino Uno. One of them is connected to magnetic current sensors and receives current data from them. It converts the incoming current information into power units with the formula $P = I*V$. Then, it calculates energy consumption with the formula $E = P*t$. The ‘t’ in the calculation is decided by using the arduino IDE's clock. We have 2 loops in our code. One is for periodic calculations and the other is for averaging the current data within the periodic loop. The code loops for 1000 ms with delays to average the current in a period. We then use this information and manage time by doing the calculation with respect to 1 second. So at each period we have E = P.1. We add the periodic output at each periodic loop together to find the cumulative energy consumption. As a result, the instant and total energy used by the client is calculated by this Arduino Uno. In addition, we get the difference between the main current information from the magnetic current sensor in the main branch and the client current information from the current sensor in the client branch. After a few tries, we set a threshold, and if the difference is above this threshold, it means that there is a thief. The RX pin of the second Arduino Uno is connected to the TX pin of the first Arduino Uno, and in this way, the first Arduino Uno sends data to it. The second one sends the information to the LCD by pins. The client can see their instant and total energy on the LCD screen. Also, "Theft Detection" is written on the LCD screen in case of theft. We used ESP32 as a Wi-Fi module. We connected the ESP32 and the phone to a common Wi-Fi network. ESP32 is connected to the first Arduino Uno and receives data from its TX pin, and it sends this information to the application via Wi-Fi. We did the software-related parts of the hardware part, for example, the operations on the Arduino Uno and the Wi-Fi connection of the ESP32 with Arduino IDE.

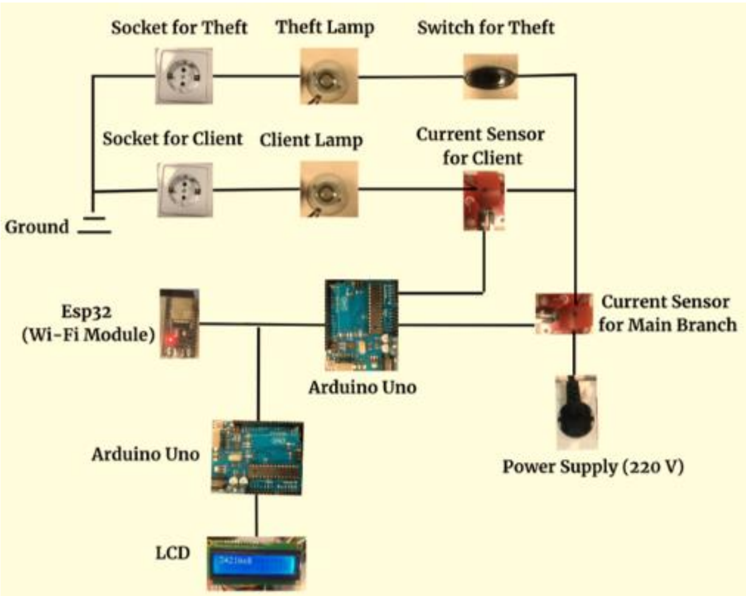


Figure 1: Schematic Diagram of our circuit

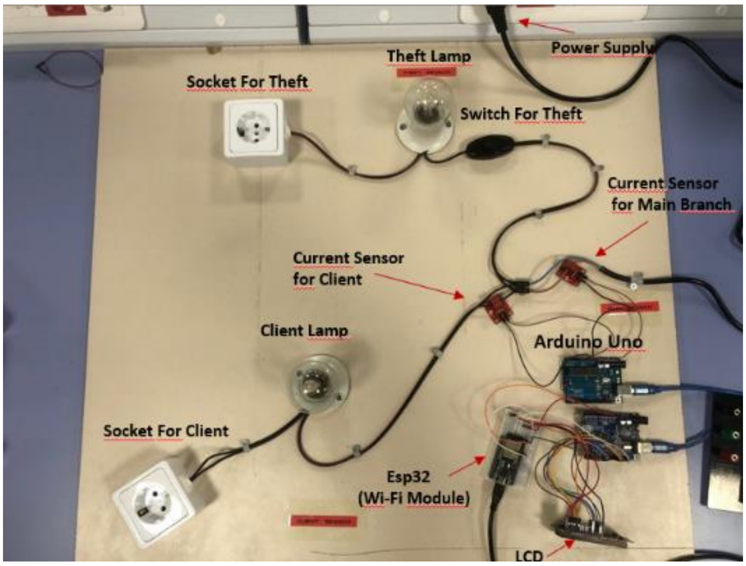


Figure 2: Circuit Design

As a Wi-Fi module, we decided to use ESP8266 at first, but we failed to connect it to Wi-Fi. Then, we tried to use Wi-Fi-based Arduino Uno, and we were able to connect it to Wi-Fi, but this time the current data from the sensors was not correct. That's why we decided to use ESP32.

Another problem was measuring the current used from the socket correctly. Each device we plug into the socket draws a different current. Furthermore, the wave characteristics of voltage for each device are different because of the circuit element variation within their hardware design. Since the current sensors use voltage data for their outputs, using root mean square calculations, which find the average of the sinusoidal waves like purely resistive devices' voltage waves, for translating magnetic current sensor outputs to actual current values was not accurate. That's the reason why we used averaging of all current sensor output values in each period to gather the information of current dissipated instead of using in root mean square calculations with the maximum current sensor output. You can find wave characteristics of voltage for different devices below.

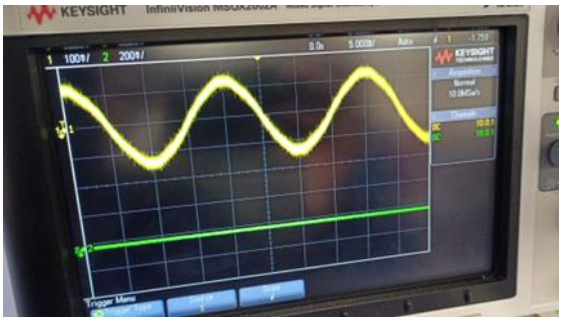


Figure 3: Wave Characteristics of Voltage for Lamp Lamp

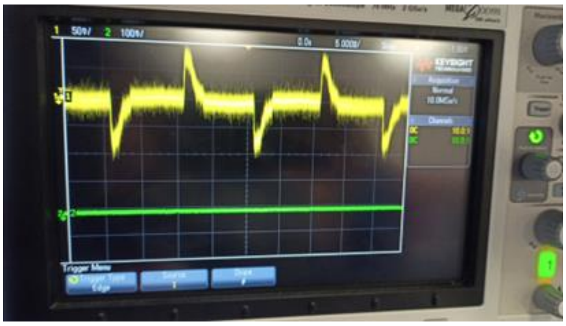


Figure 4: Wave Characteristics of Voltage for LED

Figure 5: Wave Characteristics of Voltage for Android Charger

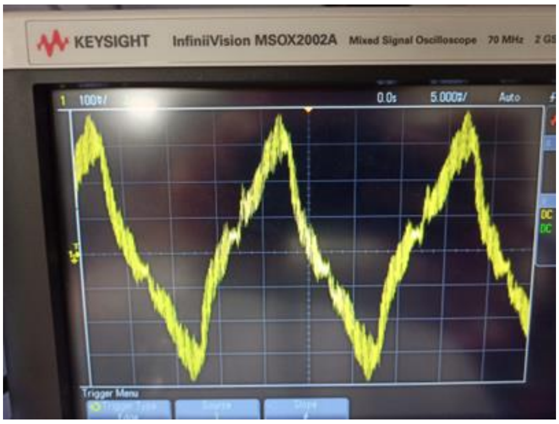


Figure 6: Wave Characteristics of Voltage for Oscilloscope

Figure 7: Wave Characteristics of Voltage for Computer Charger

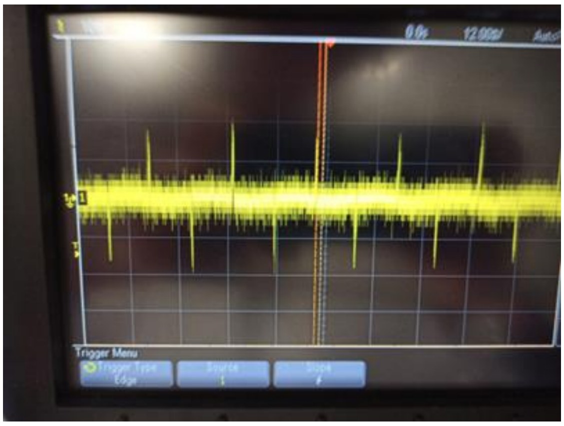


Figure 8: Wave Characteristics of Voltage for iPhone Charger

Before PDR, we made a circuit working with direct current (DC). However, after the feedback we received from the instructor in PDR, we started to work with alternating current (AC). Our old circuit also consisted of three main branches: main, theft, and client branches. In the client and theft branch, there was a lamp as an indicator that used electricity. Since we used direct current this time, we used ACS712 as a current sensor in the main and client branches. We sent the data from these sensors to the Arduino Uno, and we calculated the energy there in the same way. For theft detection, we took the difference again and made theft detection according to the threshold.

In the old version of our project, the biggest challenge we had was accuracy. Since we used 5 Volt led bulbs, the incoming current and energy were very low. That's why we had to do a lot of trials to get accurate current information, measure energy and detect theft correctly. In the end, we were able to make a circuit that gave exactly the correct results.

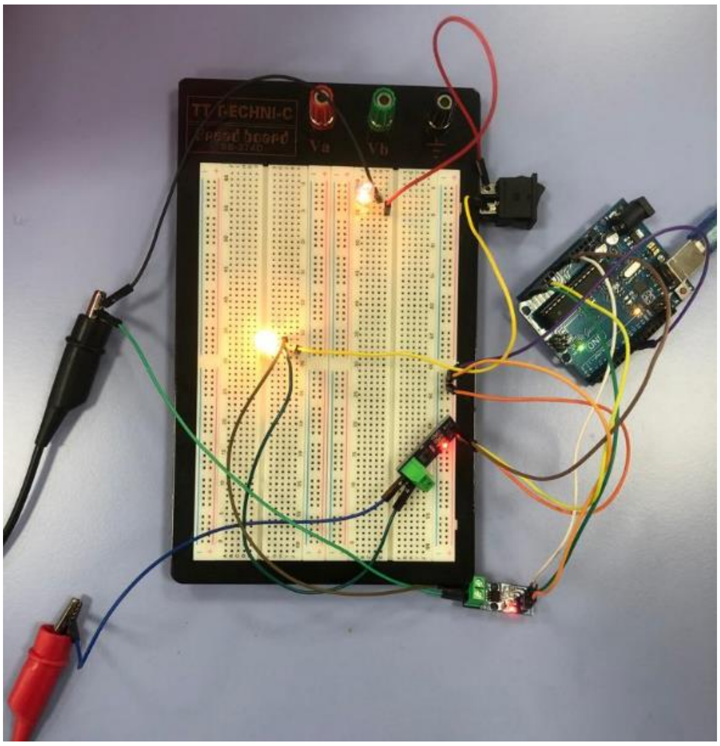


Figure 9: Old version of our project working with DC

2.2 Software Design

There is an application for the client in our project. The name of our app is Olympha. There are two main modes in our application: safe and theft mode. In the safe mode, which is the green screen, the client can see their current and total energy usage at any time. When theft is detected, the phone will be notified by the application and the application will switch to theft mode. The theft mode, which is the red screen, gives a warning message: "THEFT ALERT". In both of the screens, the client can see their total and instantaneous energy usage. In addition, the amount of energy used by the thief appears in the notification in the theft mode. Our app receives instant energy consumption value and theft detection information from Arduino Uno via a common Wi-Fi. You can find the stages of our application below.

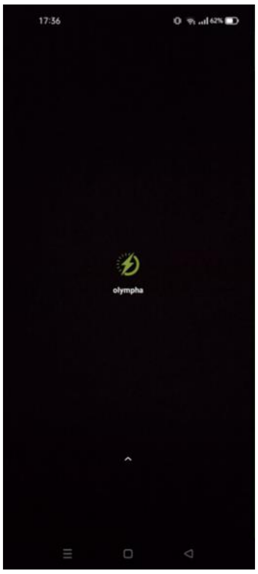


Figure 10: 1. Stage: The app is in safe mode.

Figure 11: 2 Stage: The client can see their energy consumption in safe mode.

Figure 12: 3. Stage: There is a notification.

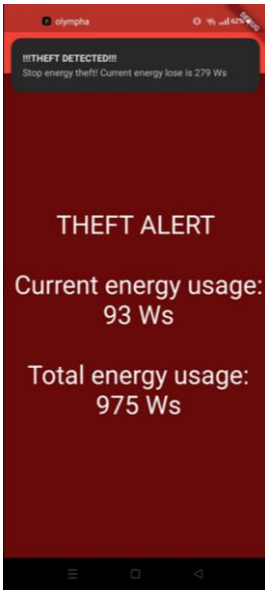


Figure 13: 4. Stage: The client can see their energy consumption and a theft alert in theft mode.

In the first stage of our software design, we created the app using MIT App Inventor which is an app development tool. It is very easy to write an app in MIT App Inventor because it allows application development with block coding methods. It uses a graphical user interface (GUI)) and allows users to drag and drop objects to create an app [8]. We first connected our application to a common Wi-Fi address with ESP32, and we directed our application to the IP address where ESP32 sends the information. Our application again had two modes, safe and theft mode. In safe mode, the user could see the instantaneous energy consumed. In case of theft, the application switched to theft mode, and a warning was displayed.

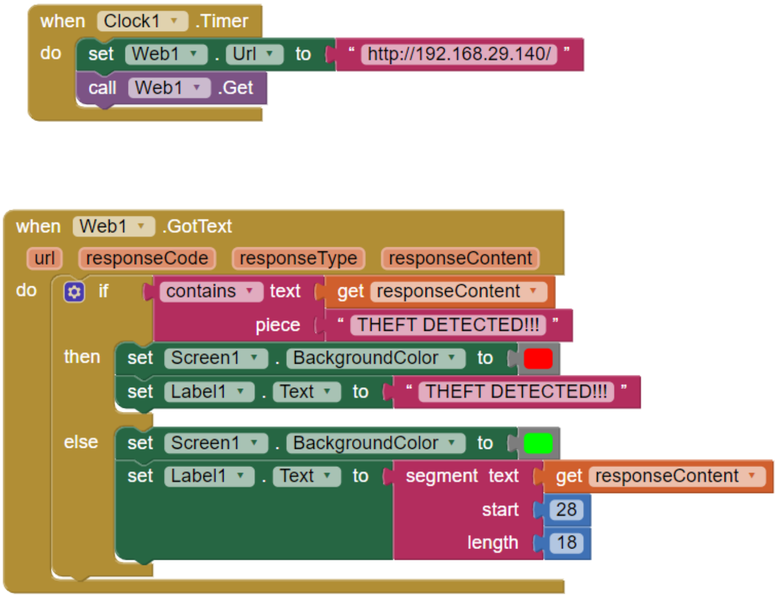


Figure 14: Our app at MIT App Inventor

Figure 15: Safe Mode

Figure 16: Theft Mode

Then we improved this prototype app and re-write the application in Visual Studio with Dart language and Flutter by using Android Studio as a debugging tool. This upgrade was necessary because MIT app inventor does not actually set up an application on the mobile phone, it uses a virtual system. We first created classes for different screen modes. We designed theft and safe screens by using these classes. Then we simulated the screen change by using buttons. We then automated this change by using time as an indicator. After we finished our initial design of the app, by using http dart library we connected our code to the Wi-Fi module Ip. We merged the screen classes in the main class and managed automation of mode change, wifi connection and data updates within. For the variables we used throughout the code we opened another globals.dart class. This class helped categorise the global variables. After we implemented the functions of the initial mit app in the flutter app we developed new features. We added the class noti.dart to send notifications to notify users about the theft detection. We designed our notification in this class. We then gave the name “olympha” to our original app and designed the app icon. We set the app icon using the Android Studio features.

Although we do the energy consumption calculations periodically in Arduino Ide, managing the cumulative energy usage and calculating the theft energy consumption was mainly done on the application side. The data of cumulative energy consumption is sent to the app every second. We hold the data of total energy dissipated, periodic energy usage and theft energy consumption value in globals.dart. We read the Wi-Fi module output and update these numbers within main.dart. Wi-Fi module output is transformed into a string using Json features and then splitted using string functions and put in the form of an array. We read the array into our code and manipulate it. The array has 2 parts. The first portion either holds the information of theft or data received information, the second part always holds the cumulative energy consumption data. Update of values are done right after data reading happens.

Initially the app has the safe mode screen opened at t=0. The app is refreshed every second by using the cron dart library and reads Wi-Fi module data. When the data from the wifi module has the string “THEFT DETECTED!!!” screen mode changes to theft screen and notifications are sent. On the notification bar, one can see how much energy is being lost. If the app works in the background, the notifications can be seen on the lock screen.

There was an issue with the screen automation, normally variable updates can trigger screen ui updates with set state function; however, in our case the variable change depends on the Wi-Fi module data. Checking the Wi-Fi module data itself is an issue because of the changing Ip. That's why we used secondly refreshes in our code. There are other solutions for similar issues. We chose to use the solution we came up with to have a more compact style. In our solution data update is done right before screen decision. The code can still use improvements, but our solutions were fast, and they solved our problems. Since we learned dart, flutter and Arduino studio usage fast and in a more non detailed way, there might be solution algorithms that we are not aware of. Later the code can be simplified and functionalized even further.

3. Analysis and Results

The most important requirements of our project are to make accurate energy measurements and detect theft. On the LCD screen and the application screen, the user can see the correct amount of energy used. In addition, our circuit can detect theft, and a warning is displayed on the LCD and application screen. We calculated the power with the formula: Power = Current * Volt. Then, we calculated the energy consumption with the formula: Energy = Power * Time. Cumulatively, the amount of energy used in each second is sent to the app.

Our project meets the requirements to a great extent. However, sometimes there are small deviations. The instant energy result may be slightly less or more than the correct value. For example, the energy consumed by a 53-Watt light bulb per unit time should be 53 Ws but in our circuit, this value varies between 45-55 Ws. This is not directly our program's fault, the given power information is a rounded and averaged value. However, our system is also faulty due to hardware parts' lack of accurateness. Current sensors have offset values, we zero them out in the beginning of our Arduino code, however while closing and opening up sockets and lamps, the current sensor offset values vary again. Project code and design is not at fault, variations happen because of individual hardwares. Therefore, the project depends highly on hardware quality, and we got our hardware from mediocre places due to no budget support. Nevertheless, for example, when we use electricity from the socket, it shows the correct energy values. If the phone is not fully charged, it draws a lot of electricity, but on the contrary, if it is fully charged, it uses very little electricity.

Another problem is that our application has a little delay. Information is displayed instantly on the LCD screen, but data does not appear instantly on the application screen, it appears with a delay of 2-4 seconds.

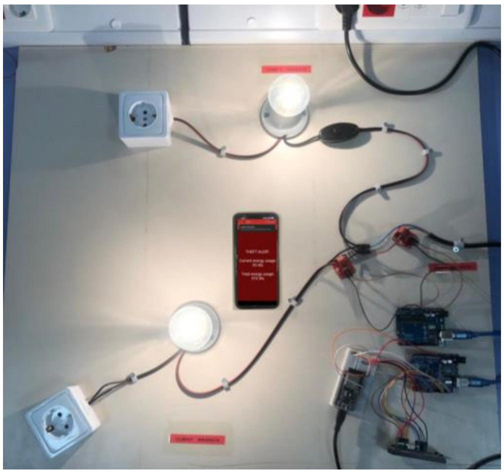


Figure 17: Accurate Theft Detection

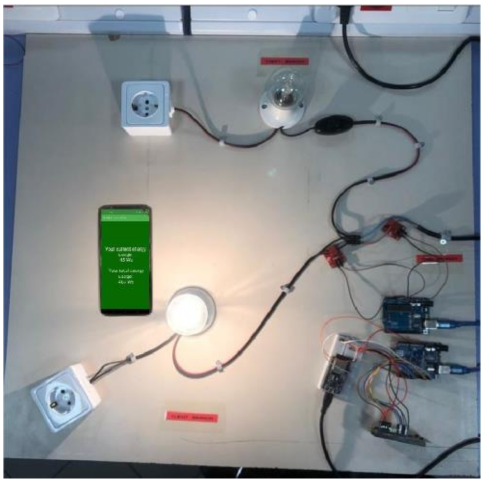
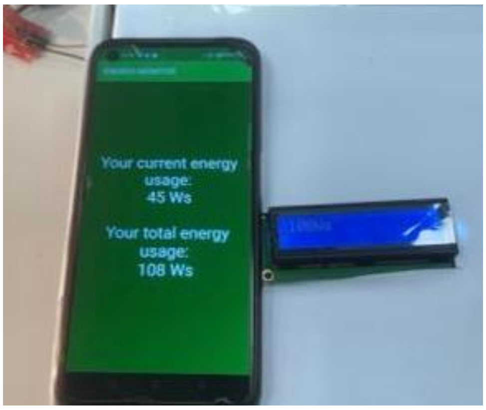


Figure 18: Accurate Energy Measurement



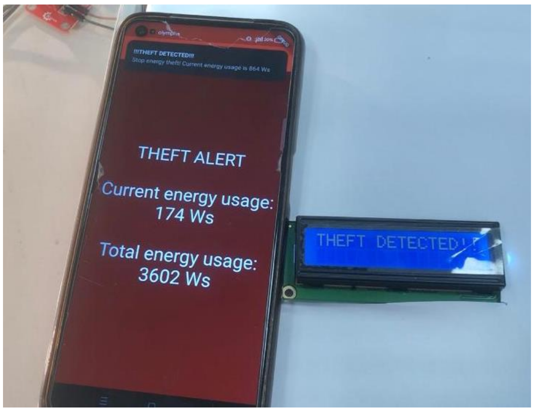


Figure 19: LCD and app screen mostly change synchronously.

4. Conclusions

In conclusion, we made a mini demo circuit of electricity theft in daily life. Our circuit notices the electricity drawn in parallel from the client branch, that is, the theft situation, and displays a warning message on the application and LCD screens. In addition, the client can see the amount of instant and total energy used on the application and LCD screens. Our project consists of the hardware part and the software part. In the hardware part, there is an electrical circuit to simulate the cases. In the software part, we have an application called Olympha.

Our project meets its objectives. For example, it detects theft correctly and makes accurate and logical energy measurements. However, there is some delay in our application. When the data changes, it instantly appears on the LCD screen, but after a few seconds it appears on the application screen. This problem is not caused by us, it is related to the speed of the Wi-Fi connection. Another minor problem is that the energy values sometimes deviate slightly from the actual value. However, these values can be ignored as they are very small values which rise up to a maximum of 10 Watt seconds.

For future work, when theft is detected in our circuit, the electricity coming to the branch may be cut off via the application. Thus, when the client is away from the circuit, it can cut off the electricity directly using the application and prevent theft. Relay module can be used for this purpose. We don't know how it works in detail, but we can cut the current through the relay module thanks to Arduino Uno and the app.

Another future work can be making our app compatible with IOS devices. Right now olympha is an android application. Since we wrote it on Flutter, it is rather easy to make it compatible with both IOS and android, but the time restrictions limited us.

The magnetic current sensors we used in the project are added to the circuit so that they pass through the cable. Therefore, it is necessary to cut the wire and pass the sensor through it. Instead, it is easier to use a sensor that can be attached directly to the cable without the need to cut the cable.

Furthermore, application interface can be improved. Application mode screens can be made more complex, and an app which can be personalised can be written.

5. References

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6. Appendices

Source codes:
https://drive.google.com/drive/u/1/folders/1jHXIByr0a9vWACLO_AbdJy4VwgbYV3j_