Koç University
College of Engineering
ELEC 491 - Design Project Proposal

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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 Arduino-based energy monitoring system that can detect energy theft. The current sensors connected to the Arduino send the total and user's current consumption value to the Arduino. The Arduino sends these values to the user's smartphone via the Wi-Fi module. In the case of safe mode, the current consumption value is shown on the user's application. In case of energy theft, theft will be detected by calculating the difference between total current consumption and the user's current consumption, and a warning will appear on the screen of the application.

Contents

1. Introduction

1.1 Concept

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.

Figure 1 Wires for electricity theft on the main electric line can be seen clearly [1]

To avoid excessive energy usage, being aware of electricity theft is necessary as well as monitoring the self-used energy. In our project, the goal is to show consumer's energy usage on their mobile application screen when there is not a case of electricity theft and showing an alert when there is a theft in the circuit. For this purpose, we will create a sample circuit containing a consumer and thief light bulbs. We will detect the energy usage and theft via current sensors connected to Arduino. The data collected from the circuit will be sent to user's application and in case of theft a warning will be seen on the application screen.

1.2 Objectives

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 an Arduino 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. We will possibly use a current sensor to get the current passing through the client's energy consumer's wire, and send this information to client's mobile application, use the basic energy consumption formula I2R to calculate the energy used and show it on the mobile phone screen

in case of safety of the circuit. On the other hand, in case of theft, we will get the current running through thief's energy consuming wire calculate the stolen energy with the same way of calculating client's energy usage and sending to user's mobile application a warning. Difference of energy usage and theft usage will be shown with a different coloured background of the application and label on the main window.

We will start with building up the circuit with one voltage source, Arduino, LCD, wi-fi module, current sensor, switch and 2 energy consuming parts. Voltage source will give the main energy to the circuit. Energy consuming parts will be parallelly connected, and the Arduino will monitor both wires to energy consumers. In case of current passage through client's consumer the current sensor which is connected to Arduino will send the instantaneous current to Arduino, which then will navigate the signal to wi-fi module. Wi-fi module will send the given signal to client's mobile phone. If the switch is turned on for theft, Arduino will detect the current passing through thief's energy consuming wire and send a signal to wi-fi module. Wi-Fi module will then send a signal to client's mobile phone. For hardware check we will use multimeter and a lcd in the early stages of the project. We will check the current passing through wires with multimeter and energy consumption value with lcd. If the values are correct on the hardware part, we will remove the multimeter from the main circuit and start with the software development.

Figure 2 Arduino UNO

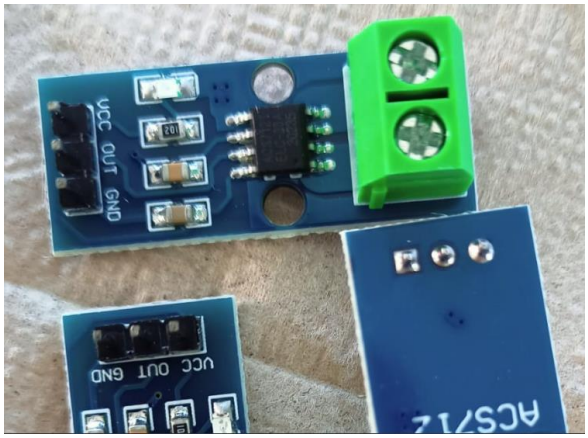


Figure 3 Current sensor

We will develop a mobile application using visual studio as an IDE and possibly use an object-oriented programming language i.e., C#, Java, together with HTML for the screen display. The application will be a simple software program which will show the energy consumption of the client on the screen display. I case of theft we will either show a popup for warning or write on the screen that there is a theft. Application can be further improved if there will be excessive time after successful hardware implementation.

At the very end of the project, user will be able to detect themselves energy consumption and can detect energy theft through a simple mobile application and act accordingly. If the hardware part sends the right signals and software part acts synchronously, we can move with adding extra details and further design the circuit part. We are also eager to expend the application and circuit for several devices if time permits it.

1.3 Background

Energy is used in every sector of the modern world, from factories to households, from streets to companies. One of the most vastly used version of energy is the electricity energy. However, electricity is not produced safe, low-carbon or cheap; it is a fossil fuel-based energy which eventually is a danger for environment. Therefore, electricity consumption should be minimalized for decreasing carbon emission, avoiding climate-crisis, whereas regulating economic expenditure.

Especially current affairs brought many countries at the edge of an energy crisis. People are more aware of the energy consumption they cause. In USA energy consumption of households cover 20% of the overall energy consumption of the country [2]. Therefore, to support governments in an energy crisis, the last people can do is supervising their household energy usage. Supervising the energy consumption of one's own self is both beneficial for the person and government in an economic sense. According to European Commission's Quarterly Report consumer bills faced rises of price over 40% compared to last year all around Europe [3]. So, to save the environment as well as unnecessary bill cost, detecting the energy consumed is a necessity.

People's awareness of their consumption will lead them to save their money; but there are more factors for people to watch their energy usage than just saving their own consumption. Electricity theft is a worldwide issue. Due to electricity theft, or in other words "non-technical losses" $96 billion per year is lost globally [4]. There are 3 well-known electricity theft methods: Tapping directly from the lines and consuming power, tampering energy meter which is a bit old-fashioned for digitalized world, and disconnection of neutral line and short circuiting the phase coil of the current transformer [5]. Detection of electricity theft is mostly done by placing current sensors on the lines.

Currently, one of the ways to detect people's energy consumption in a household by checking the electricity bill at the end of the month; however, this may lead to unnecessary electricity usage through a whole month. A more instantaneous way of checking the energy consumption will be more beneficial for the user end. An invention to detect both energy consumption and electricity theft can be a life saver for both governments and households. We aim to generate a mobile application for energy consumption and theft detection.

Even though, we want to develop an original mobile application, there already exists technologies for being aware of the instant energy consumption. To go over some ways of

monitoring energy consumption 7 examples will be examined: 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 [6]. Smart plugs work for small individual devices like blenders, irons etc; plugging one to power outlet and then attaching the appliances onto it will activate the plug to show the usage of electricity usage. Whole-home energy monitors gives a holistic view of electricity usage in households; connecting its sensors to house's electricity panel will activate monitors to track energy consumption of whole appliances in a house. Monitors with appliance recognition features are more powerful whole-home monitors with a built-in appliance recognition feature for controlling energy consumption of each individual device detailly rather than tracking the electric used by whole home cumulatively. Some monitors can detect vampire loads, which are also known as idle load electricity, that means electricity used by appliances on stand-by or sleep mode; their energy consumption ends can cover up to %25 of the total electricity bill [7]. Energy monitors connected with mobile applications is an easier and more user-friendly approach which can alert consumers about their excessive usage of power, help with programming energy consumption target, giving suggestions to save energy, powering off an appliance remotely and saving time from going and checking the actual monitor. The real-time cost tracking feature watches how client's house consumes energy and detect costs changes throughout the day or when a device is switched on or off. Using timers to manage consumption lets one to control their electric usage with time, meaning turning off a device with a software based on a timer.

In case of electricity theft, there is not a device which is vividly used. There are some machine learning or deep learning based, IoT based, and GSM based solutions that are published. Machine learning or Artificial intelligence requires lots of data and their control and turns out to be very costly or faulty for many countries. The open challenges of detecting non-technical electric usage are examined and published in "The Challenge of Non-Technical Loss Detection Using Artificial Intelligence: A Survey" by Patrick Glauner et. al. GSM based solutions are on the level of university projects and there are no implementations for their real time usage. Some solutions use the electric-meter output, while some use comparison of main energy distributor and power user's current values. One of the mostly used theft ways is altering the electric meter. India, being the host of the most electricity theft, plans to fully digitalise infrastructure they use in the country [8].

Figure 4 Digital electric meter [10]

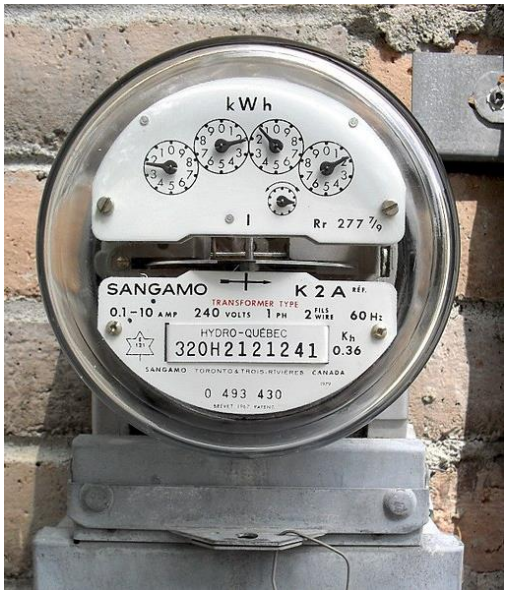


Figure 5 Old fashioned electric meter [9]

In our project we will be detecting the theft with the help of current sensors in communication with a mobile application. This will be a novelty in the area since there is not as useful way of detecting the theft. Although there are applications for energy consumption rate, being aware of the electric theft is a necessity and more beneficial then trying to lessen the usage of one's electricity since it means a whole other household is using the energy. The timeliness of the project can stretch as long as electricity used in households and its transmission done by wires.

2. S/T methodology and associated work plan

2.1 Methodology

2.1.1 Research and Plan

The main purpose of our project is to enable the consumer to monitor their own energy consumption and to understand whether electricity is used without their knowledge, that is, whether there is energy theft. According to what we researched on the internet, this situation is simulated with a circuit created using a microcontroller and a current sensor. In addition, most systems inform the consumer about the amount of energy used and the detection of energy theft via SMS thanks to GSM module. We decided to detect theft by comparing the current used by the user and the total current from the energy source. So, we will be using two current sensors in our circuit. We decided to use Arduino Uno instead of a microcontroller in our project because it already contains microcontroller and is more inclusive. By using Arduino Uno, we expect to expand our future work more comfortably. We also decided to inform the user with an application on their phone. Thus, we will add the software part to our project. This application will be able to communicate with the circuit via the Wi-Fi module.

We are planning to make a monitoring system with Arduino to monitor energy consumption and detect energy theft. Our system will consist of two current sensors, an Arduino Uno which

is a microcontroller board, a Wi-fi module, and an energy source, two light bulbs, one bulb for the consumer and the other bulb for the thief, and a switch to control the thief's light bulb. One of the current sensors will be placed in front of the consumer's bulb to measure the amount of current used by the consumer. In order to measure the total amount of current coming out of the energy source, we will put another current sensor after the energy source. These current sensors will be connected to the Arduino board and will send the instantaneous energy consumption values to the Arduino board. The Arduino board will send these values to the user's smartphone via the Wi-Fi module which will be connected to it. Moreover, we will create an application, and, in our application, the consumer can see both the amount of energy they use. In order to detect the theft, our application will calculate the difference of the values measured by the current sensors, and if there is reasonable difference, theft will be detected, and a warning will appear on the screen of our application. We do not expect the values from the sensors to be exactly equal in the absence of theft because there may be an error rate due to sensors and our circuit, also the Arduino may send these values with a delay, so the values may not reach our application at the same time. Thus, we will put a threshold for the theft and in case of the difference from the current sensors not reaching or exceeding the threshold we won't alert the user about the electricity theft, since the difference is not concerning, and we will show consumer's energy usage regarding the output current gained from the current sensor placed near the client's light bulb.

2.1.2 Ordering Components and Preparing the Hardware Part

The first step we plan to finish is the hardware part.

We will do a lot of research online to prepare circuit. We want to find sample projects online, to get inspiration from how they work and which circuit elements they use. We will compare the projects we have found and try to find the best solution for our case. In the next stage, we will search for the circuit elements that we want to use in our circuit, and we will decide specifically which brand, and which type we want to buy. Then, we will order them. For now, we are planning to make a circuit as we mentioned in 2.1.1, but we are aware of the fact that we might make changes in some places as a result of faced errors, circuit restrictions, possible extra features, the sample projects we found and the help we will receive from TA. For example, we could not decide exactly where to use the sensors and how to detect the theft on the circuit. We will try to apply our plan, and if it does not work, we will consider alternative ways. In this step, our priority is getting familiar to hardware components. We will do detailed research on Arduino, current sensor, and Wi-Fi module. We will explore how they are used, how they are connected to the circuit, and how they can send data to each other. We will also install the Arduino software on our computer, do research on how it is written. Then, we will write code for Arduino so that it can communicate with the sensor and Wi-Fi module, get data from the sensors, and calculate the difference of the values. After completing the hardware part, we want to test whether it works correctly before software part. We will use the Arduino console to test our Arduino code and whether the sensors are getting the correct value. We can test whether the sensor can measure the current value correctly by using a multi-meter. We can test the existence of theft by looking at whether there is a warning in the Arduino console when the thief's light bulb is on. After completing our test phase without any problems, we will move on to the software part, that is, the application writing part. Moreover, if time permits, we want to add an LCD to our circuit so that we can see the amount of current used on the circuit, just like the fuses in the houses, and make the demonstration more eye catching.

2.1.3 Preparing the Application Software Part

The second step we plan to finish is the software part.

The mobile application will be developed as basic as it is possible in the beginning. Expectation from it is just to show the energy consumption of the consumer and a warning in case of theft. We will develop the software independent from the circuit first, just to have a base for calculations and visuals. Then we will get the inputs from the hardware part of the project.

We plan to use Flutter and Android Studio. We want to write the code and finish the UI layer on Flutter and finish the testing and debugging on Android Studio. We will spend approximately 2 weeks to learn how Flutter and Android studio works and try starting the code from scratch. Before starting the code, we will be planning our algorithms and data structures. We may use peer programming and get help from online resources i.e. Coursera, Pluralsight.

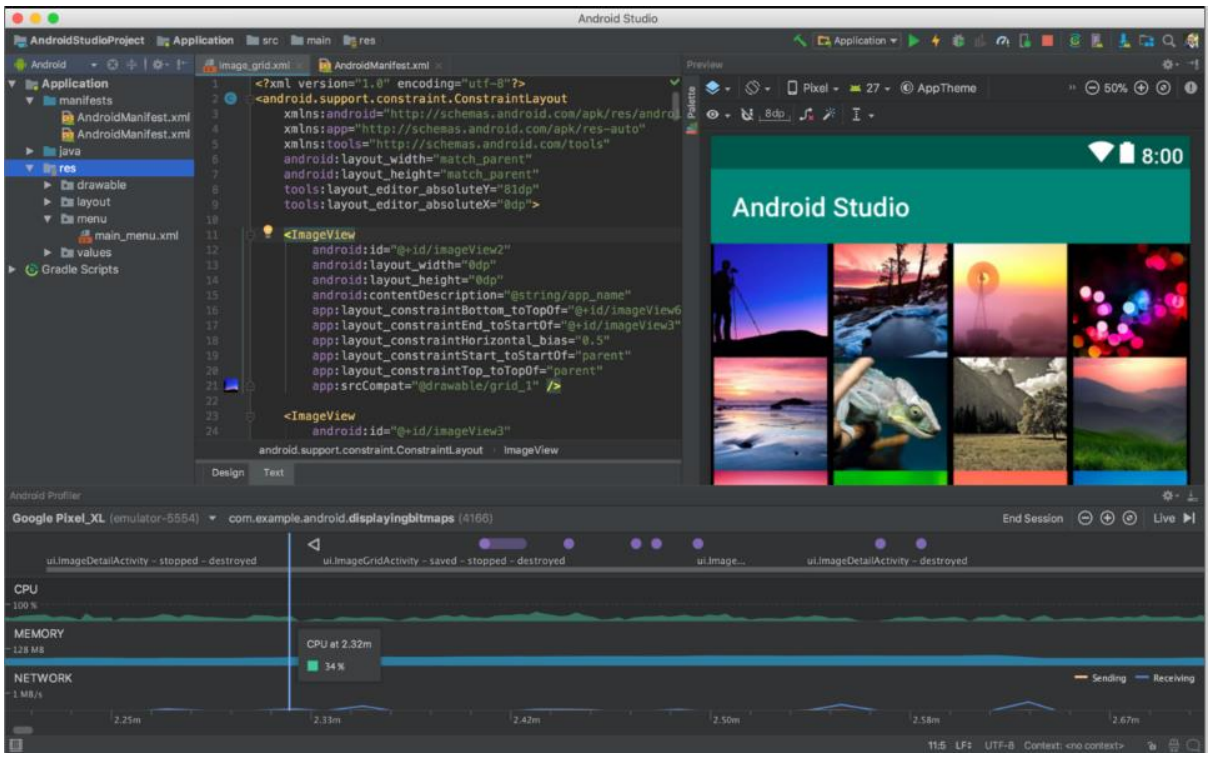


Figure 6 Android studio layout [11]

We will have a simple comparison algorithm running for the theft detection. Threshold will be determined by the developer and cannot be accessed from the client end. The inputs will be compared and if there is not a theft the regular calculation method for consumer will start running, if there is theft the warning message will be created from another method.

Regular consumer electricity usage will be calculated by basic energy formulations i.e. P=I.V. We will then use some visualization probably with HTML. It is not certain yet since the IDE we will be using is not exactly decided. The consumer's application screen will be white-green oriented, and it will show the output of energy. If time permits, we can add features to customize the UI layer from the client end and add the kwh as an extra information.

In case of theft in the beginning we are thinking about writing an alert on the screen which

will be shown when client is active on the application. Later we can move on to pop-ups for the warning to be more eye-catching and if time permits, we can send notifications to user's phone when the application is running and if we can manage when the application is not running as well.

Software is open for developments, and it does not require extra costs so it can be upgraded wildly after hardware part is over. It can be more user friendly; it can be personalized; it can be more attention grabbing. We can extend the application to be available for desktops or tablets too. These all depend on the time spend on the hardware and sensors working as expected. At this moment, we only expect the application to show user in a simple manner that there is theft, or they use an amount of shown energy, simply satisfying the project expectations.

2.2 Work Package Descriptions

Work package number	**1**	Start date or starting event:	**Week 3 (17.10.2022)**
Work package title	**Choose, Order, Get Hardware Pieces and Start Building the Circuit**		
Participant number	1		2
Participant name	Zeynep Gencer		Deniz Yılmaz
Weeks per participant	1		1

Objectives

- Getting familiar with circuit elements and building the initial circuit

Description of work

T1.1 (week 3-week 4)

- Research on sample projects and past literature.
- Do research on necessary circuit elements.
- Order circuit elements.

T1.2 (week 4-week 5)

- Test circuit elements individually.
- Research on circuit elements and their pins.
- Build the primary circuit design.

Deliverables

D1.1
A project demo or paper that is close to our project.
D1.2
Primary circuit.

Milestones

M1.1
Submitting project proposal and contract
M1.2
Order delivery finishes
M1.3
Creating the initial circuit design

Work package number	1	Start date or starting event:	Week 5 (31.10.2022)
Work package title	**Testing sensor outputs through Arduino**		
Participant number	1		2
Participant name	Zeynep Gencer		Deniz Yılmaz
Weeks per participant	1		1

Objectives

- Getting familiar with the Arduino environment
- Getting the sensor outputs on Arduino console

Description of work

T2.1 (week 5- week 6)

- Research about Arduino.
- Install Arduino on both partners' computers to be able to get familiar with the environment equally.
- Write "Hello World" on Arduino.

T2.2 (week 6- week 7)

- Get current sensor outputs individually.
- Cross check current outputs on circuit with multi-meter.

T2.3 (week 7- week 8)

- Read current sensor outputs on Arduino correctly.
- Show the outputs on console.

T2.4 (week 6- week 7)

- Research how Wifi module works.
- Connect Wifi module to Arduino successfully.
- Read the output of Wifi module successfully.

T2.5 (week 7- week 8)

- Collectively test the circuit and its outputs.
- Be sure every component communicates with each other as expected.

Deliverables

D2.1
Working Arduino code if it shows output successfully.
D2.2.
Final version of the circuit

Milestones

M2.1
Start writing the Arduino code
M2.2
Test the Arduino code and achieve successful sensor data

Work package number	1	Start date or starting event:	Week 6 (7.11.2022)
Work package title	**Creating a Simple Mobile Application**		
Participant number	1		2
Participant name	Zeynep Gencer		Deniz Yılmaz
Weeks per participant	1		1

Objectives

- Learning mobile application creation

Description of work

T1.1 (week 6-week 7)

- Research on mobile application creation.
- Choose one of the possible IDE's for usage of mobile application creation

T1.2 (week 6-week 7)

- Download Android Studio.
- Research on how Android Studio works and how testing is done

T1.3 (week 7-week 8)

- "Hello World" on new IDE
- Get familiar with the application screen outputs.
- Write some input given from the developer on the screen.

T1.3 (week 8-week 9)

- Write safe mode screen code.
- Write danger/theft mode screen code.
- Write simple calculation algorithms.

T1.3 (week 9-week 10)

- Make the dependencies and connections between safe and theft cases
- Change between safe mode and theft mode successfully by data given by developer.

Deliverables

D1.1
When given a current input from the developer from console, application shows correct energy output on screen.
D1.2
When given a theft input application shows warning on screen.

Milestones

M1.1
Getting a working application for safe case without any errors.
M1.2
Getting a working application for theft case without any errors.

Work package number	**1**	Start date or starting event:	**Week 10 (5.12.2022)**
Work package title	**Connecting Hardware and Software Parts of the Project**		
Participant number	1		2
Participant name	Zeynep Gencer		Deniz Yılmaz
Weeks per participant	1		1

Objectives

- Sending data from hardware side to software side

Description of work

T1.1 (week 10-week 11)

- Research on sensor, Arduino, and Android relations.
- Learn how Arduino communicates with mobile applications via Wi-Fi module.

T1.2 (week 11-week 12)

- Send sensor's data to Android application through Wi-Fi module on Arduino.

T1.3 (week 11-week 12)

- Get the data to software part and update the application software.
- Check if the data on application screen is correct using multimeters and Arduino console.

Deliverables

D1.1
Working application with data taken from the hardware side.

Milestones

M1.1
Obtaining data from the sensors, sending them through Wi-Fi module with Arduino to application correctly.
M1.2
Reading and evaluating consumption value and detecting theft case successfully.
M1.3
Reaching the bare minimum project description.

Work package number	**1**	Start date or starting event:	**Week 12 (19.12.2022)**
Work package title	**Tests on Software**		
Participant number	1		2
Participant name	Zeynep Gencer		Deniz Yılmaz
Weeks per participant	1		1

Objectives

- Testing the final version of Application code.
- Consider feedbacks.

Description of work

T1.1 (week 12-week 13)

- Test software outputs.
- In case of any bugs go back to primary code version and develop it again.

T1.2 (week 13-week 14)

- Do improvements if time permits.
- Satisfy feedbacks if code works already.

Deliverables

D1.1
Working application with data taken from the hardware side with satisfied feedback.

Milestones

M1.1
Achieving the successful project description.
M1.2
Satisfying feedbacks.

Work package number	**1**	Start date or starting event:	**Week 13 (30.12.2022)**
Work package title	**Tests on Hardware**		
Participant number	1		2
Participant name	Zeynep Gencer		Deniz Yılmaz
Weeks per participant	1		1

Objectives ● Testing the final version of Hardware side. ● Consider feedbacks.
Description of work **T1.1** (week 13-week 14) • Remove unnecessary hardware parts like multimeter, ampermeter etc. **T1.2** (week 14-week 15) • Do improvements if time permits. • Satisfy feedbacks.
Deliverables **D1.1** Working hardware which sends data to the application side with satisfied feedback.
Milestones **M1.1** Conclude our project.

2.3 Demonstration

Our first expectation for the demonstration is that the amount of current used by the consumer is sent to their application correctly so that the user can accurately monitor the amount of instantaneous current used.
In addition, our second expectation for the demonstration is that when we turn on the thief's lamp with the switch, a warning appears in our application so the user can detect the thief.

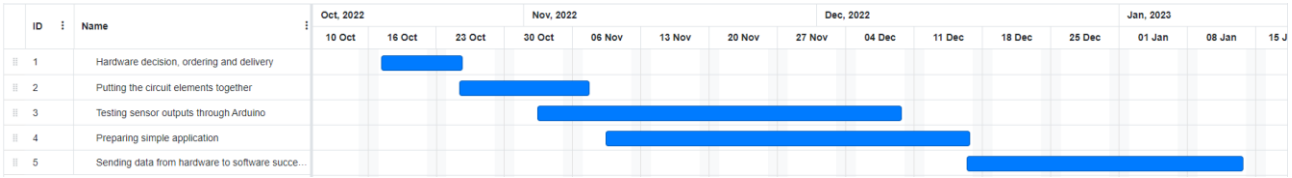
2.4 Impact

As an impact of the project, users will be more careful about their energy consumption and more eager to save their electricity usage. Moreover, the impact of our project exceeds personal interests and can be beneficial for the whole nation. Instead of paying for the stolen energy as taxes, this burden can be lifted from the bills and thieves can be punished after the detection through application.

2.5 Risk Analysis

The main risk for us is to damage to our circuit elements due to overcurrent. If we encounter such a problem, we may have to connect resistors to the circuit. Also, the sensors may not read the correct value due to noise. We think that we will have an error rate for this. To solve this problem, we will try to give a maximum threshold value to detect theft. In addition, the current value that the sensor will send to our application via Arduino and Wi-Fi module, can reach to our application with a delay, so it may not be the exact instantaneous value. However, we do think that we will update the solution in a time gap instead of instantaneous updates so this will not cause a big problem.

2.6 Gantt Chart



3. Ethical Issues

The project will agree with IEEE Code of Ethics. All the research papers used, and videos referenced have appropriate licenses. In addition, the hardware materials that we will use in this project are ethically acceptable.

4. References

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