Internet of Things Network to inhibit power theft in power distribution network



By

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Certificate

This is to certify that this thesis submitted by Muhammad Rizwan and Muhammad Hamza is accepted in its present form by the department of Electronics Quaid-i-Azam University, Islamabad for the award degree of Bachelor of Science in Electronics (BS-Electronics). The project work is supervised by Dr. Muhammad Zia.

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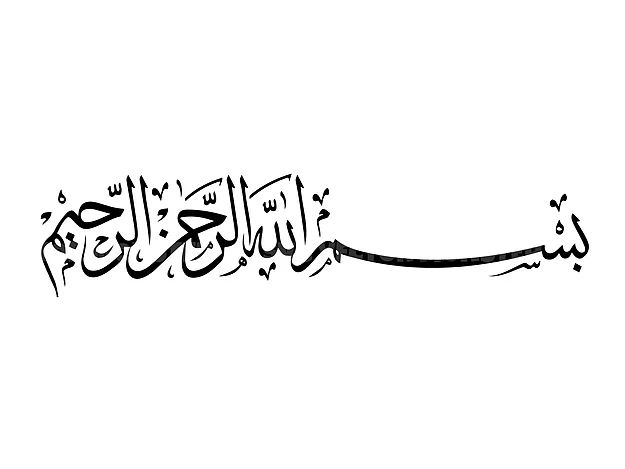
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Abstract

Electricity theft is the major problem in Pakistan and technical solution does not exist to curb the power theft. Many projects have been initiated to eliminate the power theft and none has been matured to the marketable product. This project is a step in the right direction to provide solution for the power theft by integrating off the shelf electronics modules. The proposed design uses non-invasive current sensors interfaced with microcontroller to measure the flow of current. Thus, multiple current sensors interface with smart devices connected wirelessly for a network of internet of things (IoT). In the rural are, where WiFi network is not available, data from the current sensor is relayed using long range (LoRa) wireless devices. Data from the sensor network is stored at the cloud and accessed for the analysis in real-time fashion by mobile application. The project comprises of four components. They are sensor nodes, server, data base and application.

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# Introduction

According to the recent report [1] reveals that in world economy bears about $30 billion in electricity theft. Figure 1-1 provides details of electricity theft in various countries. Employees of the electricity providers and consumers are the main culprits of power theft. Due to the power theft, power providers bear huge loss, which is eventually transferred to the customers. Consequently, average electricity cost increase. There is dire need to curtail uncontrolled power theft by new legislation and enforcement. Furthermore, available IoT technology can play pivotal role detect the electricity theft in real-time fashion. In this project, we propose an IoT based solution in order to detect power theft and generate alert in real-time manner.

Instead of bringing culprits to the justice, power companies add power theft to the line-losses. As a result, Pakistan bears line-losses up to 26%. The line-losses faced by various energy providers is shown in figure 1-2.

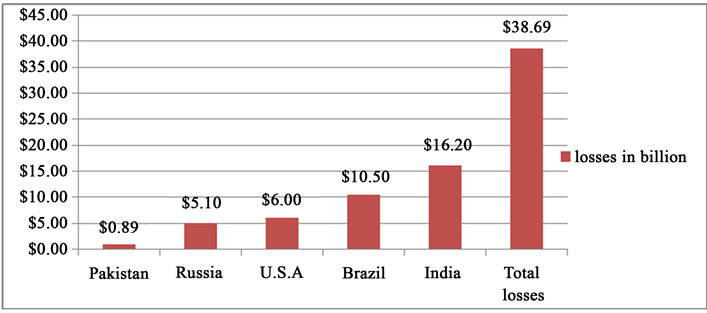


Figure ‎1‑1 World economies losses billions of dollars per year by electricity theft

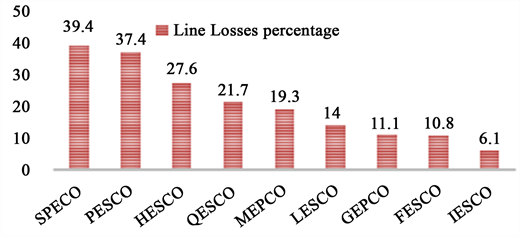


Figure ‎1‑2 Power line losses in Pakistan

## Power distribution system and thieving mechanisms

The two main kinds of power theft techniques are meter tempering and power line tempering. In meter tempering, working principle of power meters is manipulated. In line tempering, connection to the electricity meter is by passed or by local earth. These types of power theft are widespread and easy for a lay man to use. As a result of electricity theft occurring at various levels, the nation experienced economic losses and electricity theft concerns. An electricity distribution model is presented in figure 1-3. Power theft methods are described in figure 1-4 and figure 1-5.

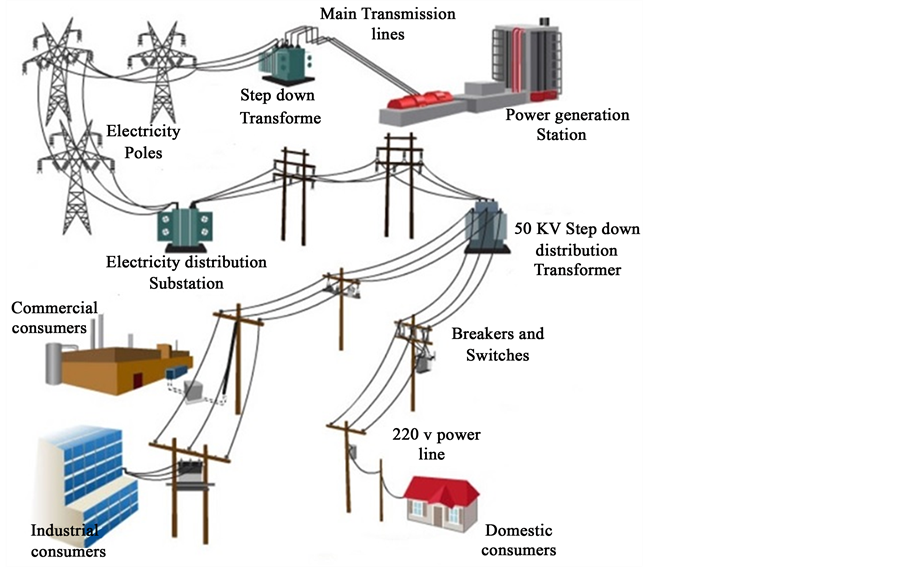


Figure ‎1‑3 Electricity distribution network

* Bypassing Electricity monitor.

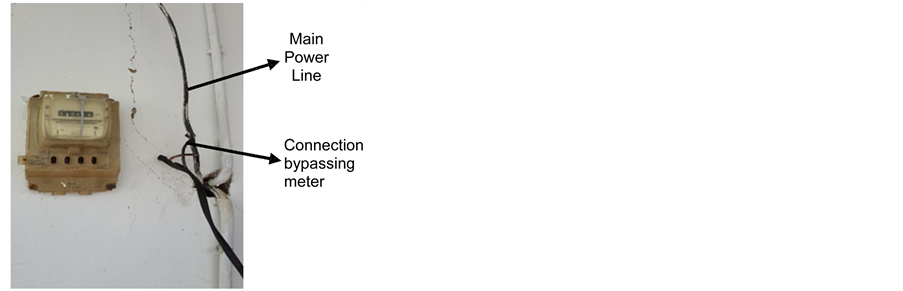


Figure ‎1‑4 Meter Bypassing

* Hooking Load Lines directly.

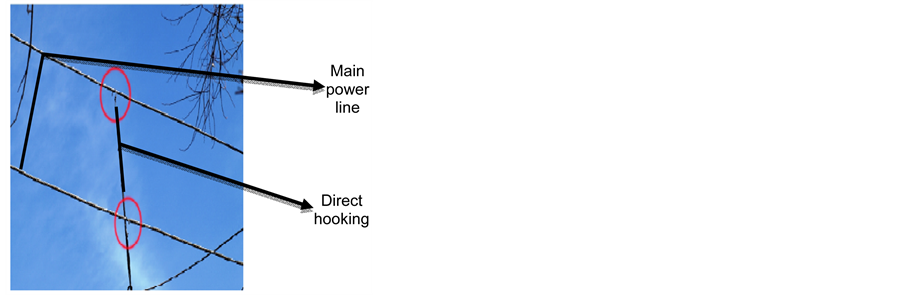


Figure ‎1‑5 Hooking

## Internet of Things

IoT is the communication between devices (things) comprised of sensors, software, controllers, and machines connected over the internet as described in the figure 1-6. The advent in this field has automated our homes and has also taken its place in the industrial world. Industrial IoT refers to machine-to-machine communication to achieve wireless control and automation. This industrial IoT is referred to as the fourth wave of the industrial revolution.

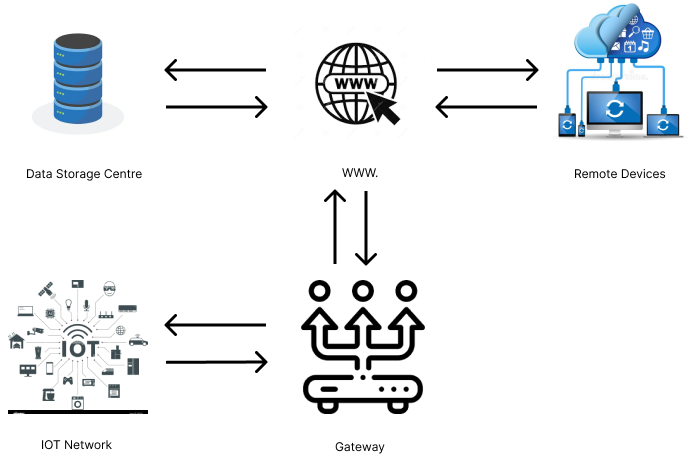


Figure ‎1‑6 Connected IoT Networks

Some common uses of Industrial IoT are:

* Smart Industrial manufacturing
* Smart power grid stations
* Smart cities
* Digital supply chains

IoT has taken its place in the market in different forms and most of the countries are expressing a great deal of investment in the field. Figure 1-7 provides the data about the fact [2].

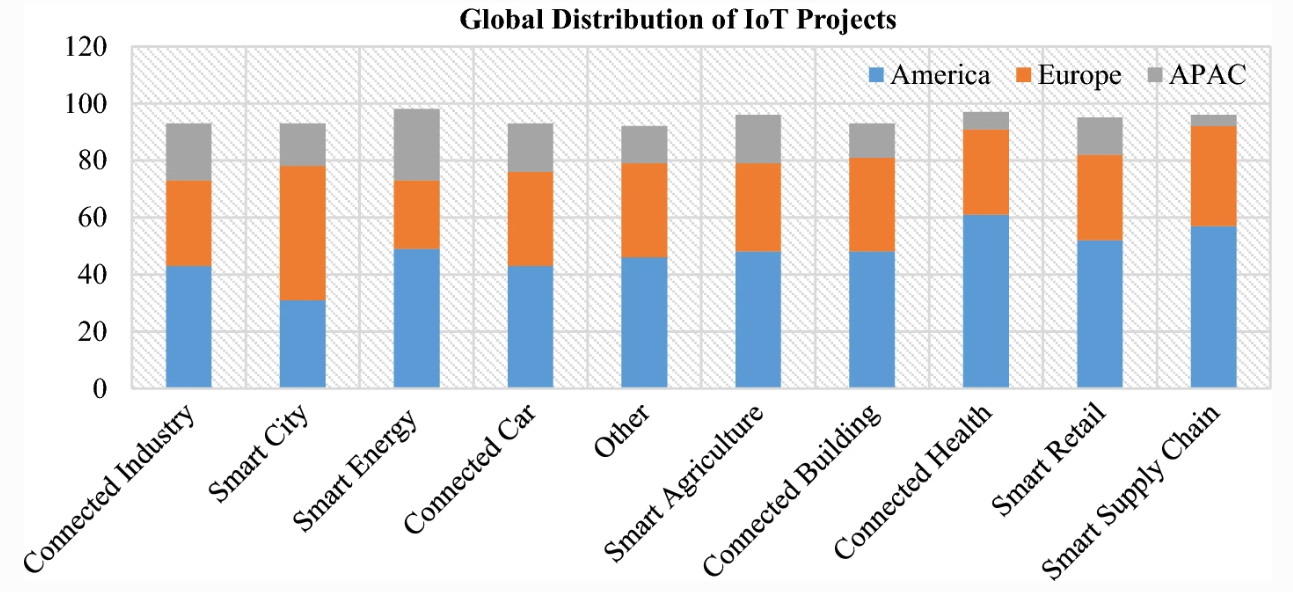


Figure ‎1‑7 Global distribution of IoT projects among America (USA, South America and Canada), Europe and APAC (Asia and Pacific region)

Figure 1-8 depicts the worldwide share in IoT field.

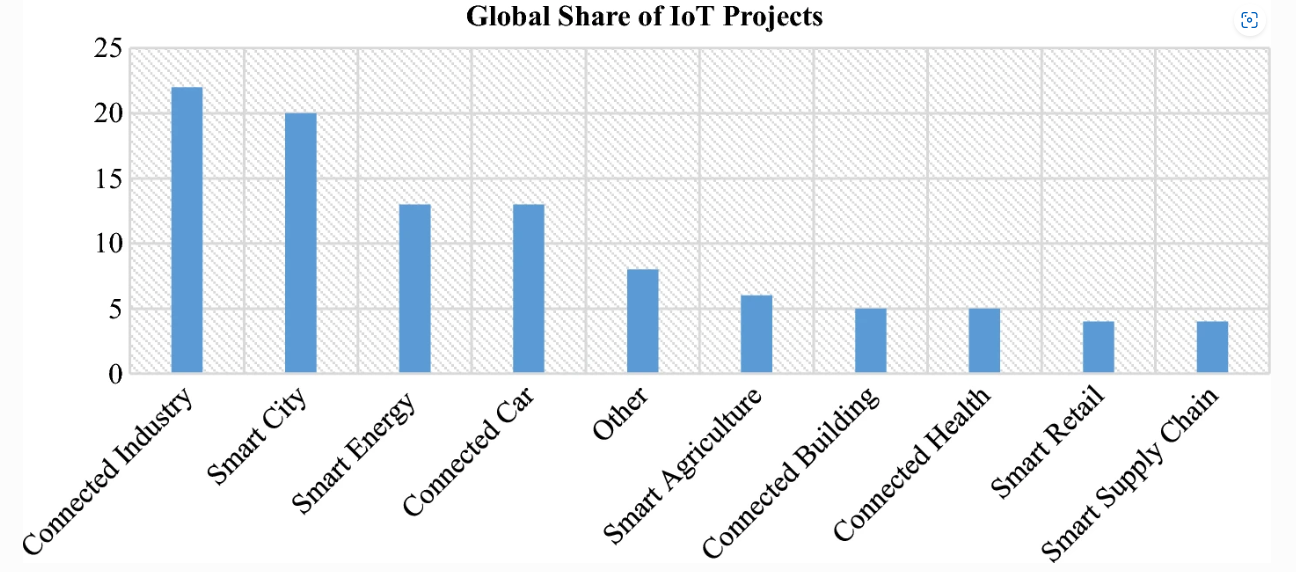


Figure ‎1‑8 Global share of IoT projects across the world

## Communication

Communication is the exchange of information between devices called transmitter and receiver. On the basis of transmitter receiver types, a system can be categorized as

* Simplex (transmitting device to receiving device communication)
* half duplex (a device can be receiver and transmitter on the basis of time)
* Full duplex (a device being transmitter and receiver at the same time)

On the basis of medium, it can be categorized as:

* Guided medium
* Unguided medium

Communicating devices are bound to follow some protocols for communication like I2C and SPI (Serial Peripheral Interface). From these, SPI is discussed since it is being used in project. And data is relayed to other devices according to a certain algorithm called topologies like star topology and mesh topology from which star topology is discussed.

### Serial Peripheral Interface

One of the most popular interfaces between microcontrollers and peripheral ICs is serial peripheral interface (SPI). SPI is a controller-node interface utilizing synchronous data exchange and full-duplex communication. Data synchronization is based upon the rising or the falling edge of the clock signal [3]. Both controller and node can simultaneously exchange their data. Both a 3-wire and a 4-wire SPI interface are currently in use and 4 wire SPI is shown in figure 1-9.



Figure ‎1‑9 Devices using 4 wire SPI

* Clock (SPI CLK, SCLK)
* Chip selection (CS)
* Controller out, node in (MOSI)
* Controller in, node out (MISO)

#### Data Transmission

To communicate, the controller firstly enables the CS signal, sends a clock signal, and chooses the node. To select the node, the controller is made to send a logic 0 on the CS bus, which is an active low signal. MISO, MOSI buses are used for full duplex data communication. Data exchange happens simultaneously through buses MOSI/SDO as output and MISO/SDI as input. The data exchange is synchronized by the clock signal [3].

## Wireless communication

The unguided medium which does not involve any physical connection between communicating devices. Since the transmitting device spreads the signal around it so the unguided signal interacts with the physical objects which leads to greater SNR ultimately leading to complex impulse responses of channel. The impulse response effects the information encoded in the signal and the range of the transmitting device.

A wireless communication system can be categorized on the basis of their range.

* Short range (Wi-Fi, Bluetooth, ZigBee, WWAN)
* Long range (LoRa, Sigfox, LTE-M, 5G)

The range is also controlled by the transmitting device itself called the transmission power of that device. The transmission power has established an inverse relation between range and the data rate.

In wireless communication to avoid any error caused by the channel response a signal is pass through a number of different encoding systems working under assigned protocols to make a wirelessly transmittable signal. Some protocols may be similar to the wired communication system but major ones differ in both and there is a great amount of complexity in the wireless transmitter/receiver. And same is the case with the receiver used in the wireless communication. The complexity has been illustrated in the figure 1-10.

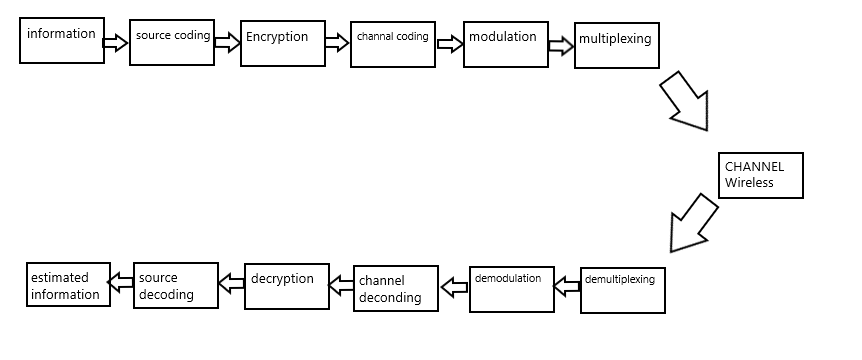


Figure ‎1‑10 Wireless Communication system

Since wireless communication plays an important role in IoT and small amount of delay can cause lag in controlling and communication cannot be real time so, in order to cope with the problem certain advancement in the field have happened over the years and communication through 5G network is the fastest and the latest one.

### 5G

In the advancement of wireless communication, the technology has developed a new generation of wireless communication standard, the 5th generation network after 1G, 2G, 3G and 4G. This generation of technology has the capability to connect every gadget, object machine, mobile and computer in a single new type of network. The technology provides fast data rates, can compensate more end users and industries, low latency and a better user experience.

It has a greater capacity to support new deployment strategies, enable new kind of online experiences, and provide novel capabilities. Due to its fast speeds, high reliability, and low latency, the mobile system will enter into new domains. It will have an effect on every business like bringing forth innovations in transportation, healthcare, farming and more. Figure 1-11 depicts the 5G capabilities.

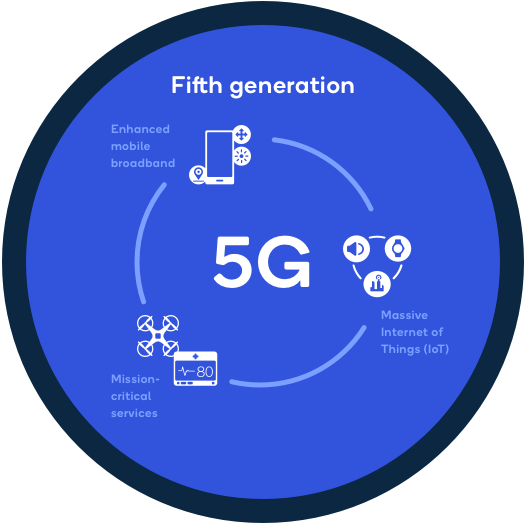


Figure ‎1‑11 5G-Wireless Communication Capabilities

### Star Network Topology

The most typical and straightforward network topology for nodes is a star network. Usually, the conduit for all network traffic is a central coordinator or concentrator. The central coordinator serves as the gateway for all network broadcasts as shown in the figure 1-12. Network traffic is reduced with the use of a star-network architecture. For the simplest communication in a star network, one requires 3 devices including 2 nodes and 1 gateway in a network with unrestricted connectivity. Nodes are also segregated from one another, which makes it simple to replace them. All network traffic may be inspected at one location thanks to centralization. The failure of the gateway causes the whole network non-functional which is a drawback of this design.

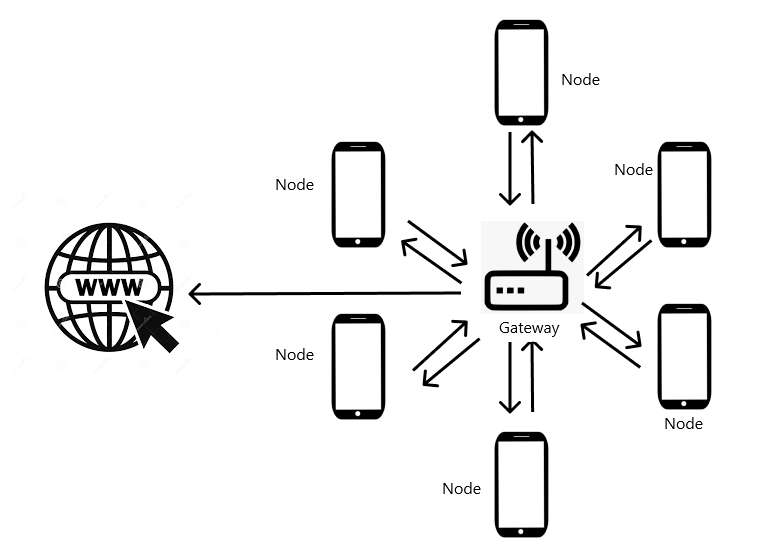


Figure ‎1‑12 Star Network Topology

## Sensor

A sensor is device responding to a physical stimulus such as heat, pressure, current and voltage. All the electrical sensors respond in the form of voltage levels as output. Sensor reads the stimulus, generates an impulse response and converts it into a voltage value which is fed into the voltmeter.

### Calibration

Sensor establishes the arithmetic relation between two measuring units and calibration is understanding that arithmetic relation between the sensor output (voltage) to the physical stimulus values. This relation is sometimes provided in the sensor guide but some error remains still and some errors are introduced when the sensor is interfaced with the voltmeter, so eliminating those error also counts as calibration.

## Analog to digital converter (ADC)

As the name specifies ADC converts the voltage signal into the digital values. It is chip performing the operation and for its functionality it is supplied with specified voltage value and the reference voltage. The conversion is based on the comparison between the reference voltage and the input voltage. The accuracy of ADC is dependent of the quantization levels and difference between maximum measurable voltage value and the minimum measurable voltage value called the measurable voltage. Quantization is slicing and leveling the measurable voltage and specifying a digital value to each level, higher the quantization, higher is the accuracy.

## Microcontrollers

Microcontroller is an integrated circuit designed to implement the specified task. It is comprised of a CPU, memory and input/output peripherals. The basic operation a microcontroller follows is the data collection from the input peripherals, passing it the processor, the processor performs the specified task on the data and then relays the data to the output peripherals.

The choice of microcontroller's processor is based upon the required functionality. Industry provides different options in term of processors ranging from the simple 4-bit, 8-bit or 16-bit processors to more sophisticated 32-bit or 64-bit processors and their choice depends upon the project. Microcontrollers usually use non-volatile memory types like erasable programmable read-only memory (EPROM), [flash memory](https://www.techtarget.com/searchstorage/definition/flash-memory) and electrically erasable programmable read-only memory (EEPROM) and some volatile memory types such as random access memory ([RAM](https://www.techtarget.com/searchstorage/definition/RAM-random-access-memory)) [4].

# Hardware

In this fast-growing world a simple goal can be achieved through number of ways and the way chosen defines the efficiency and effectiveness of the goal. Same is the case in hardware electronics, many possible solutions for a given problem can be found but choosing the right one makes the project efficient and effective. In our experience choice of the way takes more time than the implementation since the project goes through certain phases of change during the period and a single hardware component that has to ability to face the changes should be chosen, this technique makes the project improvable and updateable according to new upcoming technologies as this is the requirement of fast-growing world. This chapter explains all the hardware components and its specifications in detail.

## Current Sensor

The technique used for theft detection is to measure the current flowing in the load lines because it’s the only factor of electrical-energy consumption controllable by consumer. Current sensor available today use different technique for measurement, have different range dependent on the technique used and provide accuracy dependent on range and technique used but the suitable option for the project is the use of current transformer since it’s a non-invasive device and can measure high current values.

### Magnetic current sensor

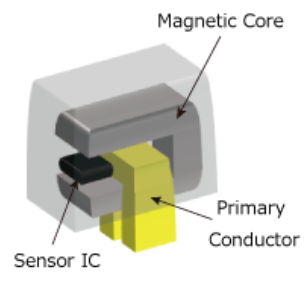
 The magnetic current sensor works on the basis that the current to be measured creates a magnetic field around the current path, which can then be detected by a sensor to determine the current's amount as shown in figure 2-1. The magnetic current sensor can be isolated internally [5]. That means there is no open circuitry that can create shocks. Certain drawbacks are associated with the use of current transformer as:

Figure ‎2‑1 Diagram of a Coreless Current Sensor

* The magnetic core potentially possesses hysteresis.
* The space is challenging because of the core (particularly because of its height).

## LoRa

LoRa stands for "long range," it defines the physical layer of the communication network. It is based upon chirp spread spectrum technology (CSS). It was created by Cycleo (patent 9647718-B2), a Grenoble, France-based business[6].

The internet architecture and communication protocol are defined by LoRaWAN. LoRa and LoRaWAN together form their own new network having the capability as Low Power, Wide Area Network (LPWAN) with a networking protocol that focuses on Internet of Things (IoT) requirements like duplex communication, security, mobility, and other localization services. On the other hand, WAN (Wide area network) is intended to connect people or companies and allows to transmit much more data than LoRa, while consuming more power. But LoRa is low power, low bit rate, and IoT enabled. The LoRaWAN data rate per channel is between 0.3 and 50 kbit/s.

### LoRa Spread Spectrum

LoRa uses its chirp spread spectrum technique. It works by creating a chirp signal that continuously changes in frequency, LoRa modulation spreads the spectrum. The chirp's frequency bandwidth is equal to the signal's spectral bandwidth. The chirp signal is firstly modulated with the data signal to be sent after which it is chipped to a higher data rate [6]. We can define the modulation bit rate, Rb, as:

Where:

* SF = spreading factor (7….to….12)
* BW = modulation bandwidth (Hz)

### Network Trial

A data table along with the street-view picture is shown in the figure 2-2 where data collected in Japan Shinjuku is used as an illustration of the of LoRa modulation performance relative to narrowband FSK [6].

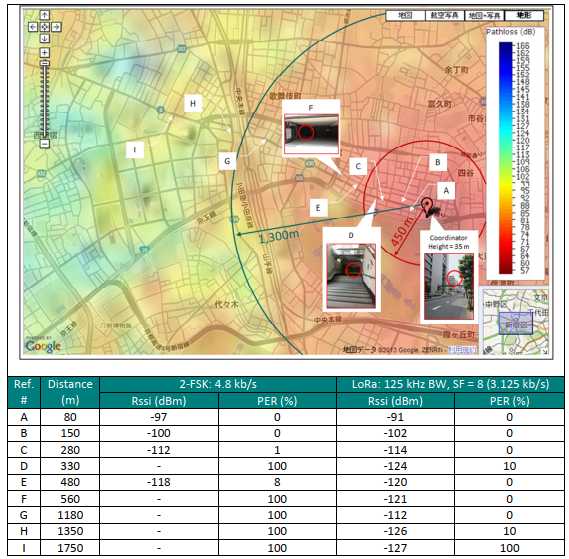


Figure ‎2‑2 Comparison between FSK and LoRa range and accuracy

The LoRa and a narrowband FSK are both configured to transmit small amount of payload at an output power of +13 dBm. It can be seen from the figure that even in populated areas the LoRa range is 3 times greater than the narrowband FSK.

### Link Budget

The link budget in delta, shown in figure 2-3 below for a fixed transmitter output power and the comparison between the link budgets that may be obtained for each modulation scheme i.e. LoRa and narrowband FSK.

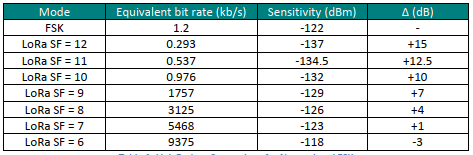


Figure ‎2‑3 Budget comparison for narrow band FSK and LoRa

It can be seen that LoRa modulation provides relatively comparable sensitivity to a traditional FSK, while transmitting at more than 4 times greater data rate [6].

## Microcontrollers

ESP-32, ESP-8266, Arduino uno and stm\_32 are the microcontrollers available in the market. Since our project has to use ADCs, WIFI and LoRa and Arduino does not have a built \_in Wi-Fi, ESP-8266 has only one ADC, STM-32 is powerful and expensive than ESP-32, But ESP-32 has 16 ADCs, built-in Wi-Fi and is a Lora compatible device and inexpensive than STM-32.

### 2.3.1 Features [7]

* 802.11 b/g/n
* TX/RX over Wi-Fi
* Station and SoftAP
* Bluetooth version 4.2
* Single/Dual-core 32-bit microprocessor(s)
* 4MB flash drive
* Internal 80 MHz oscillator with calibration
* 34 × programmable GPIOs
* 12-bit SAR ADC up to 18 channels
* 2 × 8-bit DAC
* 10 × touch sensors
* 4 × SPI
* Hall sensor
* Random Number Generator (RNG)

### Pin Diagram

Figure ‎2‑4 diagram of ESP-32

# Software

This chapter explains all the key details about the software used during the project. The word software is being used in abstract terms and will be explained in the chapter since everything discussed in the chapter is related to software.

## C++/C – Programming language

C programming language was invented to create the UNIX operating system. C is the most popular computer language.

### Applications

C was firstly used for system development tasks, especially for the operating system's program. Because C language codes execute almost as quickly as assembly language code, it was accepted as a system development language. Here are a few instances of how C is used [8]:

* Operating Systems
* Language Compilers
* Assemblers
* Text Editors
* Print Spoolers
* Network Drivers
* Modern Programs
* Databases
* Language Interpreters
* Utilities

## Arduino IDE – Hardware Programming tool

The Arduino IDE also known as Arduino Integrated Development Environment. It offers its features to other boards like the ESP-32 through its libraries in addition to a text editor for writing code, a message area, a text terminal, a toolbar with buttons for frequently used activities, and a variety of menus for Arduino. It connects to the Arduino hardware to upload applications and communicate with them [9]. To connect Arduino to the Computer Serial peripheral Interface is used SPI.

### Programming Language

The Arduino Programming Language is a C++ foundation. Sketch is a program created using the Arduino programming language. A sketch is often saved with the .ino extension (from Arduino). Your whole code is confined in 2 core functions, which is the primary difference between this and "normal" C or C++. However, every Arduino program must have at least two functions.  The first is referred to as setup (), and the second as loop () and you can have more too. While your application is running, the second is continuously called while the first is only called once at program startup. As the point of entry for a program, we do not have a main () method like you are accustomed to in C/C++ [10]. The IDE will verify that the final product is a valid C++ program after you compile your design and will essentially preprocess it to include the missing glue. The remaining code is standard C++, and all legitimate C++ code is also legitimate Arduino code. The fact that you can launch your program over numerous files, but they all need to be in the same folder, is one difference that might give you problems. If your software becomes really large, this limitation could be fatal, but at that point switching to a native C++ configuration will be simple and feasible.

The built-in libraries that are a component of the Arduino programming language enable simple integration with the features offered by the Arduino board.

### Uploading

Before uploading the sketch firstly select the port by entering the menu Tools > Board and Tools > Port, in the submenu Port, select the port mentioned as COM1 or COM2).

The Arduino bootloader, a small program installed onto the microcontroller’s board, used to upload sketch. It helps by declining the need of any external hardware for uploading. Boot loader works for a brief time and when microcontroller turns on it uploads the recent sketch onto it.

### Serial Monitor

This displays the transmitted information from the board using a serial or USB port. To send any command to the board, input it in the menu and press enter. Choose the baud rate that corresponds to the data rate supplied by the board [11].

## JavaScript – Web development Language

JavaScript is a programming language utilized to make complex web pages and advancing their functionality. It is the third tier of common web technologies, the first two (HTML and CSS) [12].

For client-side programming the most used language is JavaScript. For the script's code can only be used in wen if it has a its link to a HTML document.

* It implies that a web page may not be a simple HTML document, but rather may contain program that can interact with users, interact with browsers, and generate HTML content on the go.
* When a user performs a task on the web page, JavaScript runs, which compares all the entries that the task created to the stored entries and are sent to the web server if the entries are recognized.
* Use of JavaScript is used to create, capture events that are initiated by the user, such as button clicks, link navigation, and other explicit or implicit activities.

### JavaScript Development Tool

Java scripting can be done by using a basic text editor like Notepad. There is no need of a special compiler because it is an interpreted language used in a web browser.

Several businesses have developed JavaScripting tools. Some are listed here:

* **Apps script**: this editor lets you design custom google sheets for data storage.
* **Microsoft FrontPage**: Microsoft created the well-known HTML editor FrontPage. Web designers can create interactive websites with the help of the JavaScript capabilities that FrontPage also offers.

#### Apps Script

Google sheets allows user to edit, control and use as database by setting its working through the Google Apps Script. Custom menus, dialogues, and sidebars can be added to Google Sheets using Apps Script. Additionally, you can combine Sheets with other Google services like Calendar, Drive, and Gmail, as well as build your own custom functions for Sheets. The majority of Google Sheets scripts use array manipulation to communicate with a spreadsheet's cells, rows, and columns.

# Working Mechanism

This chapter describes all the hardware and software implementation details in step by step.

## System Model

As shown in the figure 4-1, complete project model is given where the sensor reads the value, nodes process the value and send it to server using LoRa transceivers. Then the server/gateway uploads the data to the cloud which can be monitored as it is or can be monitored through an android smartphone.

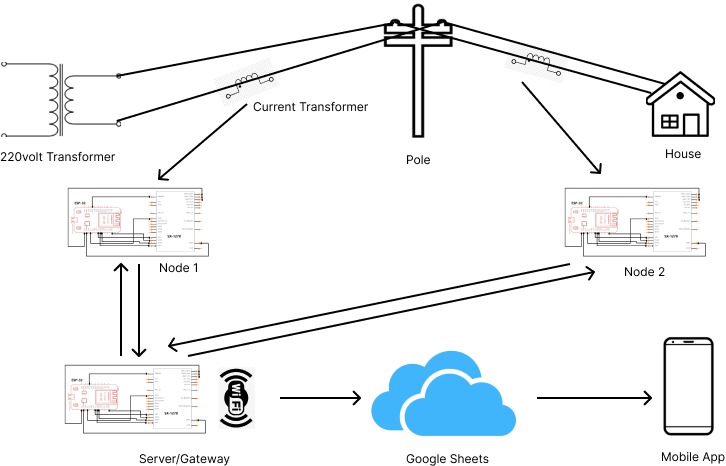


Figure ‎4‑1 Complete model of the project

## Node

In the project node is a device which monitors and senses the load lines using a Current transformer and relays it to the ESP-32 where the assigned algorithm calculates the current being transferred through the wire and create a data packet in the form of string. The string is then encoded with all the protocols assigned by LoRaWAN which is then relayed to the LoRa connected to the ESP-32 by serial-peripheral interface. The LoRa on the node side only acts as transmitter and sends the data in 433MHZ band. Since the node is comprised of certain modules working together and their interfacing with each other is a major thing which is discussed in the coming topics.

### Sensor-Controller Interfacing



Figure ‎4‑2 Sensor-Controller interfacing

#### Apparatus

* Current transformer 2 x 30A to 30mA converter
* ESP-32
* Resistor 100 ohm
* Resistor 2 x 10 Kohm
* Connecting Wires

#### Procedure

* The Current transformer is firstly passed over the load line which outputs the current by providing it the gain of 0.001.
* Which current is then passed through the 100-ohm resistor called the bypass resistor to create the voltage according to ohm’s law.
* Since AC is flowing through the resistor which means the voltage created across is also alternating and has positive and negative values. The measurable voltage range, that ESP-32 provides is 0 to 3.3 volts. So, this problem is coped by providing DC offset.
* DC offset of 1.55 volt is being provided using the 3.3-volt output from the ESP-32 and using the voltage divider of two 10-Kohm resistors. Using low value of resistor can draw more than 12mA of current from ESP-32 which is not providable.
* Now the voltage value created from the current reading plus the DC offset is relayed into the ESP-32 ADC pin where the calculations take place.
* Same procedure is followed by other current transformer in use by the project figure 4-2 shows the circuit diagram of sensor interfacing.

### Controller Calculation

When ESP-32 receives voltage value at the ADC pin it compares it with the Vref normally it is 1100mV and is adjustable and can be applied from an outer source, and outputs a 12-bit value since the ADC being used is 12-bit. The ADC’s accuracy can be adjusted to the minimum level of 8-bit.

The library used for current calculation is EmonLib.h (Energy monitoring). it is an open-source library made by the OpenEnergyMonitor company which has its own energy monitoring devices. Library also takes care of the calibration and requires a calibration value to adjust the readings. For a known current source was taken and with repeated trials were made to get the sensor calibrated with the controller.

The ADC pic and its calibration is done by the API, **elemon\_1.current(ADC\_pin, calibration-value)** where elemon\_1 is a class and current is the object. The API, **Irms = elemon\_1.calcIrms(no. of readings)** calculates the currentcalculates the RMS voltage and calculate from it, the RMS current value and returns the measured RMS current.

### Controller-Transmitter Interfacing

The LoRa transmitter is connected to Microcontroller using serial-peripheral interfacing, explained in the above chapter and figure 4-3 explains the physical connection of the interface. When RMS current has been calculated by the controller its is then sent by LoRa and the library used is coding is **LoRa.h**. the function used in sketch are, **LoRa.setPins(reset-pin, ss-pin, I/O),** which establishes an SPI connection between microcontroller and LoRa module and **LoRa.begin(433E6)**  set the transceiver frequency to 433MHz. **LoRa.setSyncWord()** this function synchronizes the clocks of microcontroller and LoRa module. If the LoRa is not interfaced correctly it starts generating signal using LED. After the successful interfacing the data is compiled by functions mentioned below.

* **LoRa.beginPacket()**
* **LoRa.print("microcontroller-ID")**
* **LoRa.print(Current-value)**
* **LoRa.print("#")**

And the packet is then sent by the function **LoRa.endPacket().** As every LoRa module spreads the signal everywhere around it in the same frequency band for that an ID is attached with the data.

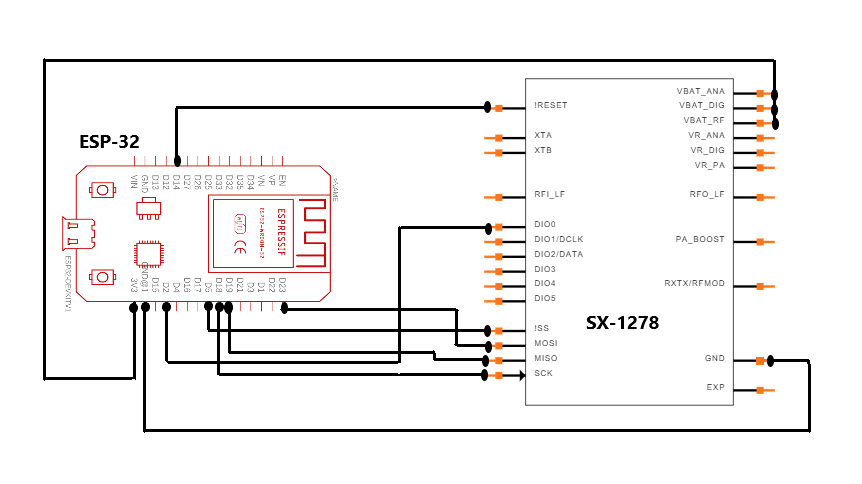


Figure ‎4‑3 ESP-32 LoRa Interfacing

## Gateway/Server

In this project sever is a device which receives the data packet sent by the node side LoRa module. Server Decrypts the packet by following algorithm and then uploads it to cloud data-base using Wi-Fi. The Server side is comprised of LoRa receiver and an ESP-32.

### Controller-Receiver Interfacing

The hardware interfacing is same like that of node side. The LoRa is connected to controller using SPI. But here the LoRa is set as receiver by using the library **LoRa.h**. the function used in library are, **LoRa.setPins** which required three parameter for pin number assignment. The pins to be assigned are reset pin, ss pin and I/O pin. **LoRa.begin(433E6)** is a function that establishes an SPI connection between microcontroller and LoRa module and set the transceiver frequency to 433MHz. **LoRa.setSyncWord()** this function synchronizes the clocks of microcontroller and LoRa module. certain setup procedure is followed to setup the connection. If the setup is malfunctional it also produces an alert using LED.

After the connection has established LoRa can receive data from any other LoRa using the function **LoRa.readString()** but the packet with the required information key can only be parsed. The data from the transmitter is decrypted by using function **LoRaData.substring()** subtracting the data upto to certain length from the packet received and is encrypted again to be sent to cloud data-base.

### Uploading

The uploading is performed using the HTTP protocol by microcontroller using the libraries **WiFi.h** and **HTTPClient.h**. WiFi.h lets the microcontroller connect to the specified internet connection. For that the SSID and the Password is stored in microcontroller for establishing the connection by the function **WiFi.begin(ssid, PASSWORD)** and **WiFi.status()!= WL\_CONNECTED** checks for the connection establishment.

After which Uploading is simply sending a get request to the data-base made by calling **http.begin(URL)** and **http.GET()**. The get request has its protocol i.e., making the suitable URL with all the information required by the website. And taking in view that all the protocols are fulfilled when making that URL.

The URL contains:

* Google sheets link
* Google sheets ID
* The parameters

## Database

Google Sheets stores the data and the data id formatted by the app script written in JavaScript as shown in the figure 4-4. The sheet only gives access to the users with the specified key and monitors for any get requests received. Apps Script executes the function **doGet()** whenever a user accesses an app or whenever a program sends the app an HTTP GET request (e). The e argument in this situation denotes an event parameter that may include details about any request parameters. In our case the **e.parameter** is being used and it is a key/value pair object with the corresponding values for the request parameters. When there are several values for a parameter, just the first value is returned. Simple formatting sets the rows and columns and **new Date()** function assigns date to every node-data. When a user accesses server dataBase through mobile application his credentials are stored in the google firebase as shown in the figure 4-5.

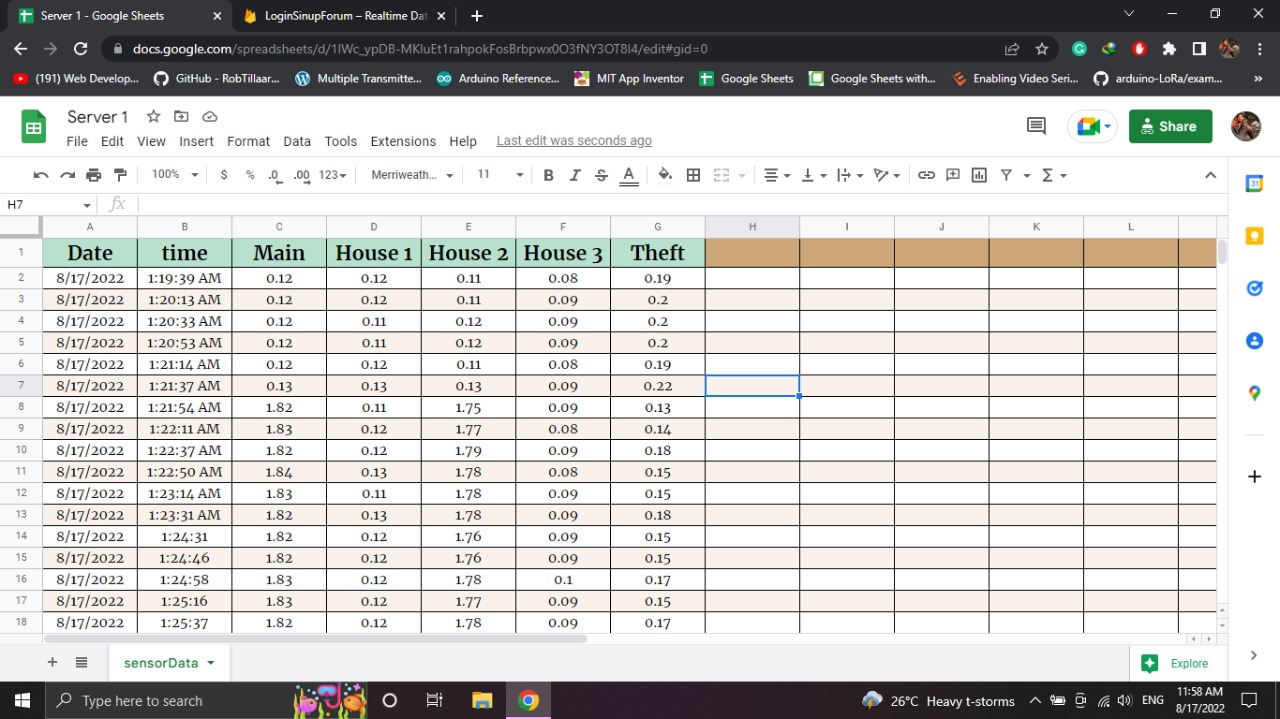


Figure ‎4‑4 Server Database

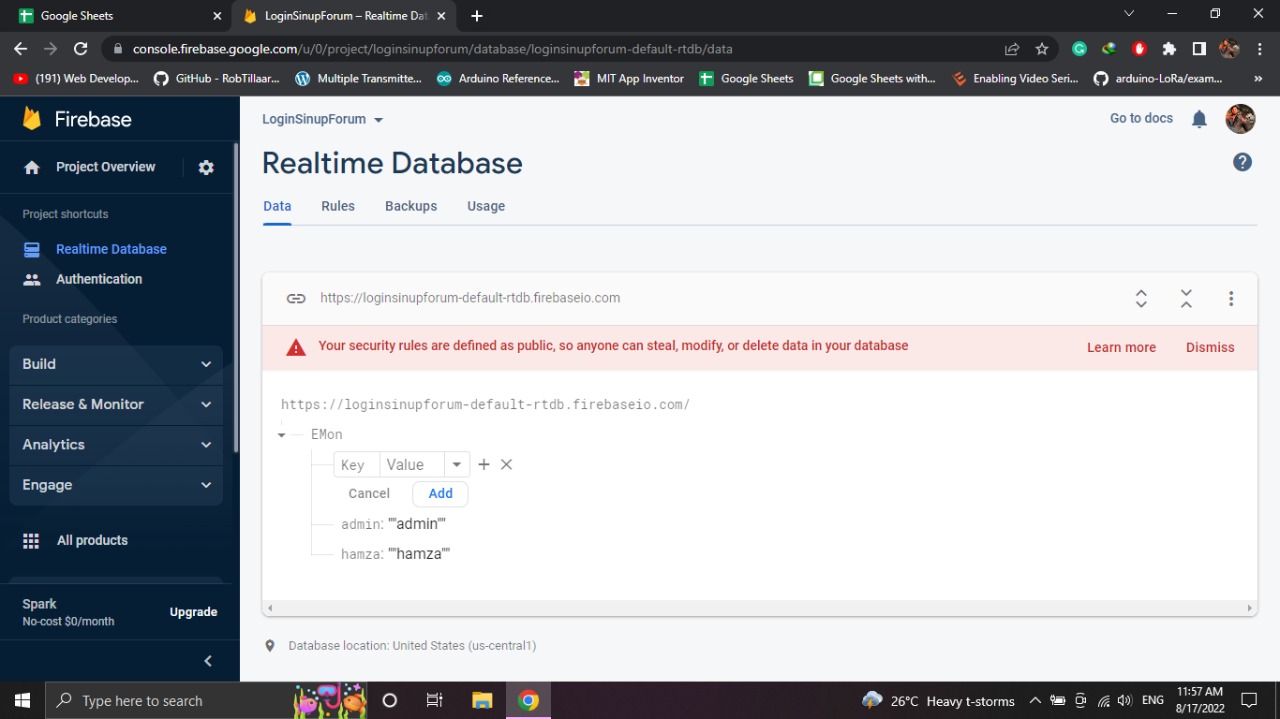


Figure ‎4‑5 App Database

## App Designing

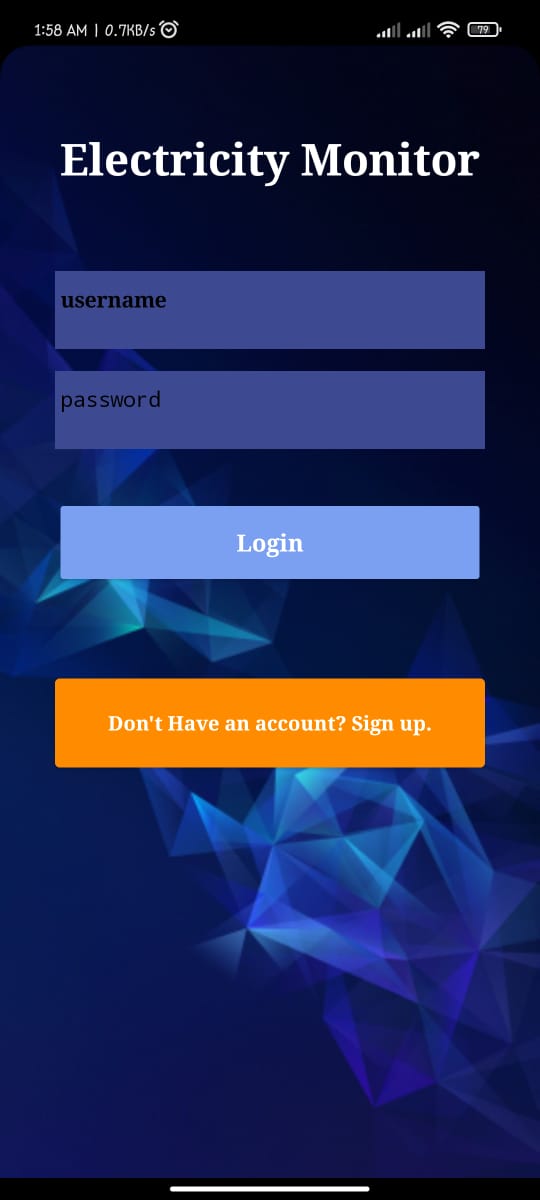
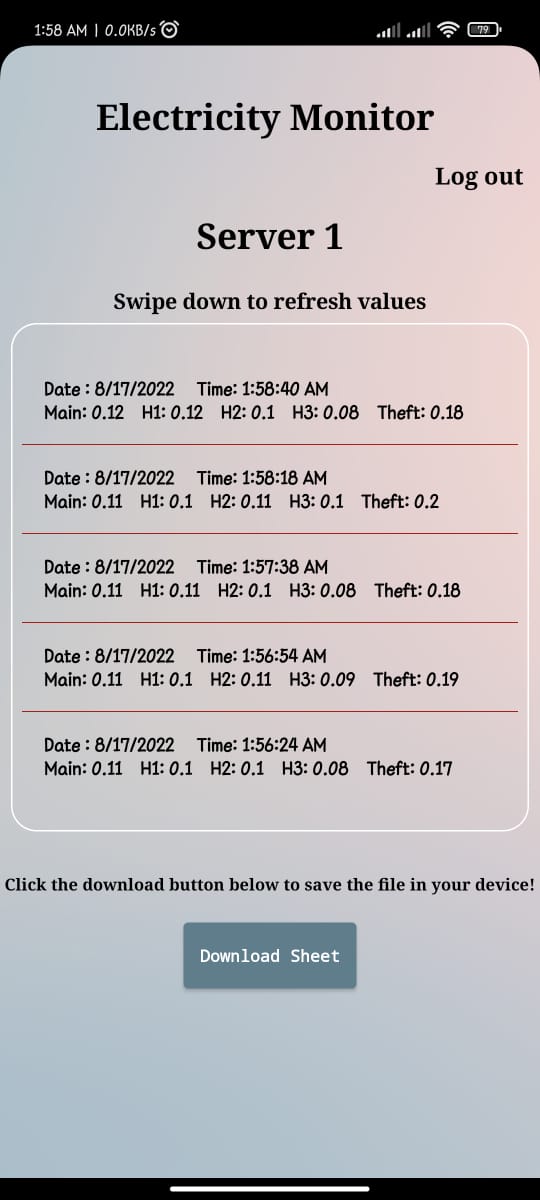
App is designed by the help of a tool called MIT app inventor. The major function used in the app are **web.get ()** which sends the get request to the google sheet and fetches the data. After which the **webGotText ()** removes the header**,** converts the data into csv table text in the form of a list. Secondly, its formatting function arranges the data in horizontal lists and thirdly each element of list is stored into a new vertical list and is deployed onto the screen as shown in the figure 4-4a below.

The main screen also has a refresh button which can sync the app manually.

The log in screen matches the data entered in the required fields with the data stored in the firebase. The screen is shown in the figure 4-4b.

The sign-up screen collects the data from a new user and stores that data into the firebase for later matching usage. The screen is shown in figure 4-4c.

Figure ‎4‑6 a: Main Screen b: Login Screen c: Signup Screen



## Self-made System

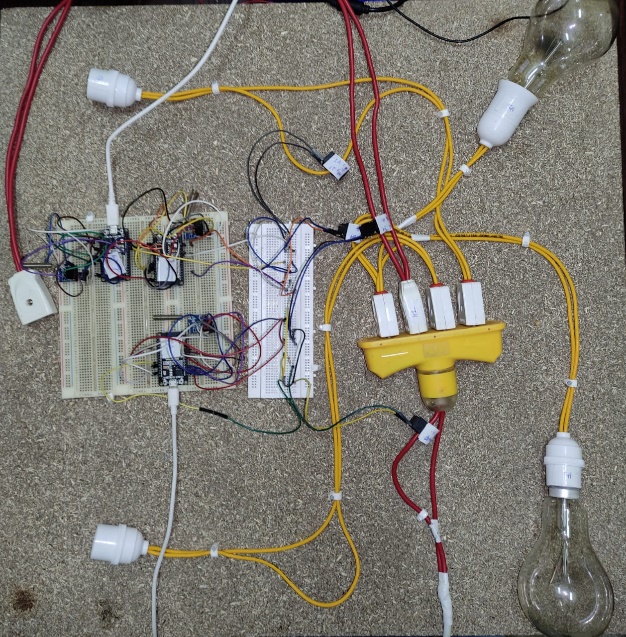
Figure 4-7 shows the self-made project.Figure 4-8 shows project flowchart

Figure ‎4‑7 Self-made System

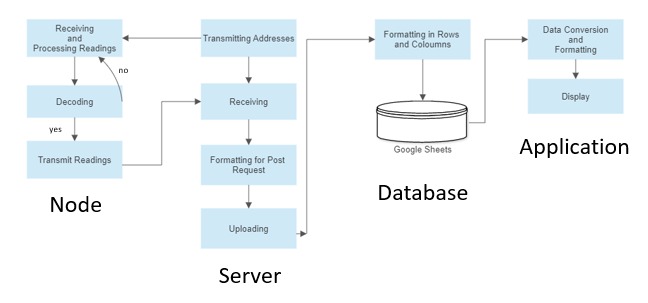
****

Figure ‎4‑8 Project flowchart

Results

Results show that if there is no current passing through the load lines the value that we receive is between 0.20 to 0.25 so it can be said that this much current is not readable by the nodes. Above this level, reading are almost inline with the readings taken by the multimeter with the maximum error of 1%. Data on the database is uploaded every 3 seconds from nodes. Figure A shows the data stored on the database.

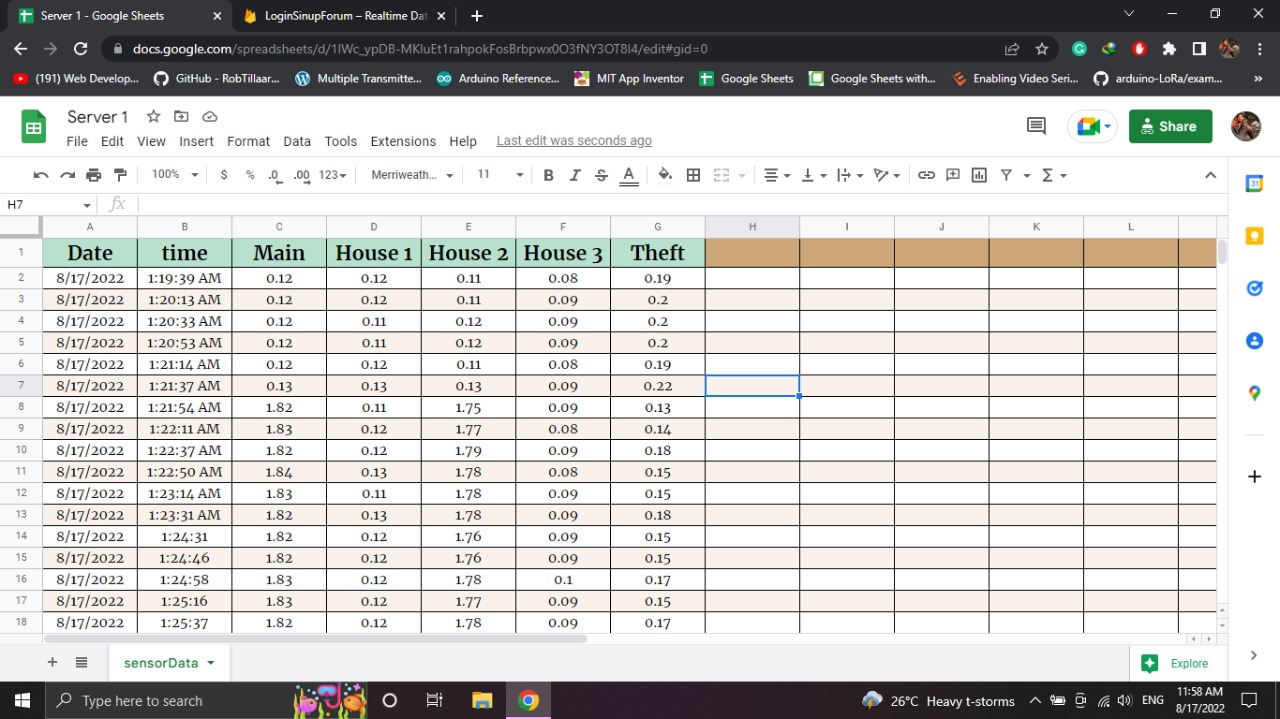


Figure ‎4‑9 results

Advancements to the system

It is the main feature of the project that it is upgradeable to become a complete digital meter and can replace the analog meters being used today in Pakistan. The upgrade just requires a simple voltage sensor like zmpt-10x series for its upgrading and a few changes in the programs uploaded.

Cost Analysis

|  |  |  |
| --- | --- | --- |
| **Device** | **Quantity** | **Price per unit in Rs** |
| **Node** | **1** | **3560/-** |
| ESP-32 | 1 | 1200/- |
| LoRa (sx-1278) | 1 | 1450/- |
| Current transformer | 2 | 450/- |
| Resistors | 3 | 10/- |
| **Server/Gateway** | **1** | **2650/-** |
| ESP-32 | 1 | 1200/- |
| LoRa (sx-1278) | 1 | 1450/- |
| **Total Cost** | **1** | **6210/-** |

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Appendix A

Node

Appendix A contains the program uploaded in the node A. which is same for all other nodes.

/\*

LoRa Node A

Current value below 0.25 is not measurable.

\*/

// including libraries

#include <SPI.h>

#include <LoRa.h>

#include <EmonLib.h>

//pin configuration for LoRa SX-1278

#define nss 5

#define rst 14

#define dio0 2

//pins for sensors connected to Node A for currunt reading

#define H\_1 34

#define \_main 27

//taking two instances from the library for our sensor to get values

EnergyMonitor emon1**;**

EnergyMonitor emon2**;**

// Flag set by callback to perform read process in main loop

volatile bool doRead **=** **false;**

//assign addresses for LoRa Transmission for master node and Node A and two //varriablefor authentication request

byte MasterNode **=** 0xFF**;**

byte NodeA **=** 0xBB**;**

int recipient**;**

byte sender**;**

//defining varriable for currunt reading and incoming request from gateway

String currentReadings **=** ""**;**

String incoming **=** ""**;**

//variable store currunt readings

float house1**,**Main**;**

void setup**()**

**{**

LoRa**.**setPins**(**nss**,** rst**,** dio0**);**

**if** **(!**LoRa**.**begin**(**433E6**))**

**while** **(**1**);**

LoRa**.**onReceive**(**onReceive**);** // register the receive callback

LoRa**.**receive**();** // put the radio into receive mode

//instances setting up pins and calibration value

emon1**.**current**(**H\_1**,** 4.9**);**

emon2**.**current**(**\_main**,** 4.9**);**

**}**

void loop**()**

**{**

//Dummy varriables to get value from sensor for making the value stable

float dummy1 **=** emon1**.**calcIrms**(**1480**);**

float dummy2 **=** emon2**.**calcIrms**(**1480**);**

// parse for a packet, and call onReceive with the result:

**if** **(**doRead**)**

**{**

readMessage**();**

// Set flag back to false so next read will happen only after next ISR event

doRead **=** **false;**

LoRa**.**onReceive**(**onReceive**);**

LoRa**.**receive**();** //again put the radio in recieve mode

**}**

**}**

void onReceive**(**int packetSize**)**

**{**

**if** **(**packetSize **==** 0**)** // if there's no packet, return

**return;**

doRead **=** **true;**

**}**

void readMessage**()**

**{**

incoming **=** ""**;**

recipient **=** LoRa**.**read**();**

sender **=** LoRa**.**read**();**

**while** **(**LoRa**.**available**())**

incoming **+=** **(**char**)**LoRa**.**read**();**

**if** **(**recipient **!=** NodeA **&&** sender **!=** MasterNode**)**

**return;** // skip rest of function

int Val **=** incoming**.**toInt**();**

**if** **(**Val **==** 10**)** //check if the request is for the node

**{**

house1 **=** emon1**.**calcIrms**(**1480**);**

Main **=** emon2**.**calcIrms**(**1480**);**

currentReadings **=** house1**;**

currentReadings **+=** "/"**;**

currentReadings **+=** Main**;**

currentReadings **+=** "#"**;**

sendMessage**(**currentReadings**,** MasterNode**,** NodeA**);**

currentReadings **=** ""**;**

**}**

**else**

**return;**

**}**

void sendMessage**(**String outgoingSendingMessage**,** byte MasterNode**,** byte NodeA**)**

**{**

LoRa**.**beginPacket**();** // start packet

LoRa**.**write**(**MasterNode**);** // add destination address

LoRa**.**write**(**NodeA**);** // add sender address

LoRa**.**print**(**outgoingSendingMessage**);** // add payload

LoRa**.**endPacket**();** // finish packet and send it

**}**

Appendix B

Server/Gateway

This appendix contains the code uploaded in the server/gateway.

/\*

Master LoRa Node(Gateway)

\*/

#include <WiFi.h>

#include <HTTPClient.h>

#include <SPI.h>

#include <LoRa.h>

#include <NTPClient.h>

#include <WiFiUDP.h>

WiFiUDP ntpUDP**;**

// Selecting Europe for getting real-time time stamps

NTPClient timeClient**(**ntpUDP**,** "de.pool.ntp.org"**,** 18000**,** 60000**);**

// Flag set by callback to perform read process in main loop

volatile bool doRead **=** **false;**

// flag set for conforming that gate has recived data from every node

boolean flag1 **=** **false,** flag2 **=** **false;**

//Setting up LoRa Pins

#define nss 5 //GPIO 5

#define rst 14 //GPIO 14

#define dio0 4 //GPIO 4

//Setting up WiFi connectivity.

const char**\*** ssid **=** "QAU"**;**

const char**\*** PASSWORD **=** "Abcd1dcbA2"**;**

//setting up credentials for dataBase which in our case google excel sheets

const char**\*** APP\_SERVER **=** "script.google.com"**;**

const char**\*** key **=** "AKfycbyk4DJzRuIarOcUs07uNzmrpvUvuUK\_EJCI6X\_2FRTf9FjlCZQUn9MM2PpLjagG-1qq8w"**;**

String serverTime **=** ""**;**

String distPnt **=** ""**;**

String path1 **=** ""**;**

String path2 **=** ""**;**

String path3 **=** ""**;**

float theft**;**

//assigning addresses to the gateway and senders

byte MasterNode **=** 0xFF**;**

byte NodeA **=** 0xBB**;**

byte NodeB **=** 0xCC**;**

//varriable for storing and for sending data to cloud

String incomingValues **=** ""**;**

String currentMain **=** ""**;**

String currentA **=** ""**;**

String currentB **=** ""**;**

String currentC **=** ""**;**

// Tracks the time since last event fired

unsigned long previousMillis **=** 0**;**

unsigned long int previoussecs **=** 0**;**

unsigned long int currentsecs **=** 0**;**

unsigned long currentMillis **=** 0**;**

int interval **=** 1 **;** // updated every 1 second

int Secs **=** 0**;**

void setup**()**

**{**

WiFi**.**begin**(**ssid**,** PASSWORD**);**

pinMode**(**2**,** OUTPUT**);**

**while** **(**WiFi**.**status**()** **!=** WL\_CONNECTED**)**

digitalWrite**(**2**,** HIGH**);** //if WiFi will not be connected LED will remain turn ON

timeClient**.**begin**();**

digitalWrite**(**2**,** LOW**);** //as the WiFi got connected LED will turn OFF

LoRa**.**setPins**(**nss**,** rst**,** dio0**);**

**if** **(!**LoRa**.**begin**(**433E6**))**

**while** **(**1**);**

// register the receive callback

LoRa**.**onReceive**(**onReceive**);**

// put the radio into receive mode

LoRa**.**receive**();**

**}**

void loop**()**

**{**

**if** **(**doRead**)**

**{**

readMessage**();**

// Set flag back to false so next read will happen only after next ISR event

doRead **=** **false;**

**}**

currentMillis **=** millis**();**

currentsecs **=** currentMillis **/** 1000**;**

**if** **((**unsigned long**)(**currentsecs **-** previoussecs**)** **>=** interval**)**

**{**

**if** **(** Secs **>=** 5 **)**

Secs **=** 1**;**

**if** **(**Secs **==** 2**)**

**{**

String message **=** "10"**;** //an identifier msg act as ID for security

//will send request to node A for values

sendMessage**(**message**,** MasterNode**,** NodeA**);**

LoRa**.**onReceive**(**onReceive**);**

LoRa**.**receive**();** //sets the Radio in recieve mode again

**}**

**if** **(**Secs **==** 4**)**

**{**

String message **=** "20"**;** //an identifier msg act as ID for security

//will send request to node B for values

sendMessage**(**message**,** MasterNode**,** NodeB**);**

LoRa**.**onReceive**(**onReceive**);**

LoRa**.**receive**();** //sets the Radio in recieve mode again

**}**

previoussecs **=** currentsecs**;**

Secs **=** Secs **+** 1**;**

**}**

timeClient**.**update**();**

serverTime **=** timeClient**.**getFormattedTime**();** //get current time

**}**

//send a signal to each node for requesting the data of sensors.

void sendMessage**(**String outgoingRequestForData**,** byte MasterNode**,** byte otherNode**)** **{**

LoRa**.**beginPacket**();** // start packet

LoRa**.**write**(**otherNode**);** // add destination address

LoRa**.**write**(**MasterNode**);** // add sender address

LoRa**.**print**(**outgoingRequestForData**);** // add payload

LoRa**.**endPacket**();** // finish packet and send it

**}**

//call back function will confirm that here's some data on the gateway to be recieved

void onReceive**(**int packetSize**)**

**{**

**if** **(**packetSize **==** 0**)** // if there's no packet, return

**return;**

doRead **=** **true;**

**}**

/\*

this function will read all the data and check if data is received from both node and prepare

the data to be uploaded to the sheets.

\*/

void readMessage**()**

**{**

// read packet header bytes:

int recipient **=** LoRa**.**read**();** // recipient address

byte sender **=** LoRa**.**read**();** // sender address

incomingValues **=** ""**;**

**while** **(**LoRa**.**available**())**

incomingValues **+=** **(**char**)**LoRa**.**read**();** //reading data message

**if** **(**sender **==** NodeA**)** //checking if data is from NodeA

**{**

int pos1 **=** incomingValues**.**indexOf**(**'/'**);**

int pos2 **=** incomingValues**.**indexOf**(**'#'**);**

path1 **=** incomingValues**.**substring**(**0**,** pos1**);**

distPnt **=** incomingValues**.**substring**(**pos1 **+** 1**,** pos2**);**

flag1 **=** **true;**

**}**

**if** **(**sender **==** NodeB**)** //checking if data is from NodeA

**{**

int pos1 **=** incomingValues**.**indexOf**(**'/'**);**

int pos2 **=** incomingValues**.**indexOf**(**'#'**);**

path2 **=** incomingValues**.**substring**(**0**,** pos1**);**

path3 **=** incomingValues**.**substring**(**pos1 **+** 1**,** pos2**);**

flag2 **=** **true;**

**}**

**if** **(**flag1 **==** **true** **&&** flag2 **==** **true)** //checking if data is recieved

**{**

theft **=** **(**path1**.**toFloat**()** **+** path2**.**toFloat**()** **+** path3**.**toFloat**())** **-** distPnt**.**toFloat**();**

accessToGoogleSheets**();**

flag1 **=** **false;**

flag2 **=** **false;**

**}**

**}**

void accessToGoogleSheets**()**

**{**

HTTPClient http**;**

String URL **=** "https://script.google.com/macros/s/"**;**

URL **+=** key**;**

URL **+=** "/exec?"**;**

URL **+=** "time="**;**

URL **+=** serverTime**;**

URL **+=** "&distributionPoint="**;**

URL **+=** distPnt**;**

URL **+=** "&path1="**;**

URL **+=** path1**;**

URL **+=** "&path2="**;**

URL **+=** path2**;**

URL **+=** "&path3="**;**

URL **+=** path3**;**

URL **+=** "&theft="**;**

URL **+=** theft**;**

http**.**begin**(**URL**);**

http**.**GET**();**

**}**

Appendix C

Database

This appendix contains the formatting code for the google sheets. The code given is written in JavaScript.

function doGet(e) {

    let id = '1IWc\_ypDB-MKluEt1rahpokFosBrbpwx0O3fNY3OT8I4';

    let sheetName = 'sensorData';

    var result;

    // e.parameter has received GET parameters, i.e. current measurment from differnt sensors

    if (e.parameter == undefined)

      result = 'Parameter undefined';

    else {

            var sheet = SpreadsheetApp.openById(id).getSheetByName(sheetName);

            var newRow = sheet.getLastRow() + 1;  // get row number to be inserted

            var rowData = [];

            var d = new Date();

            rowData[0] = d.toLocaleDateString();

            rowData[1] = e.parameter.time;

            rowData[2] = e.parameter.distributionPoint;

            rowData[3] = e.parameter.path1;

            rowData[4] = e.parameter.path2;

            rowData[5] = e.parameter.path3;

            rowData[6] = e.parameter.theft;

            // 1 x rowData.length cells from (newRow, 1) cell are specified

            var newRange = sheet.getRange(newRow, 1, 1, rowData.length);

            // insert data to the target cells

            newRange.setValues([rowData]);

            result =  'Ok';

            }

    return ContentService.createTextOutput(result);

}

Appendix D

This appendix contains all the coding performed on kodular app platform in form of .png file.

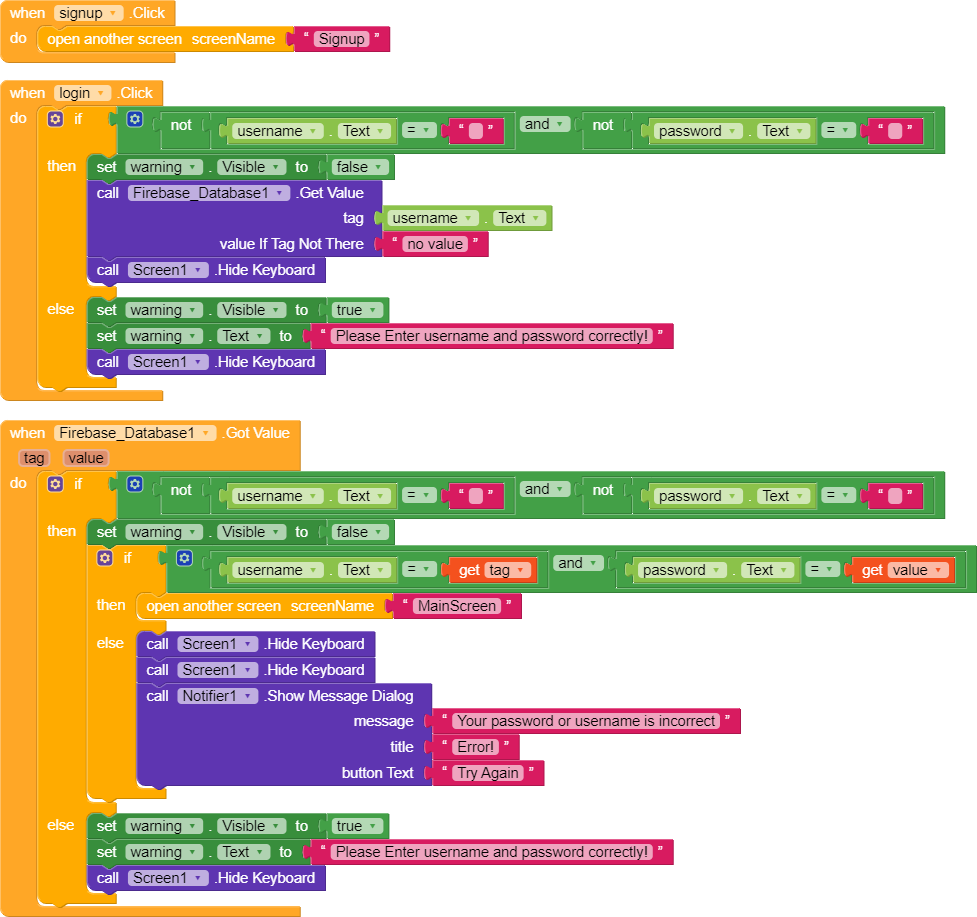


Figure A: Login screen

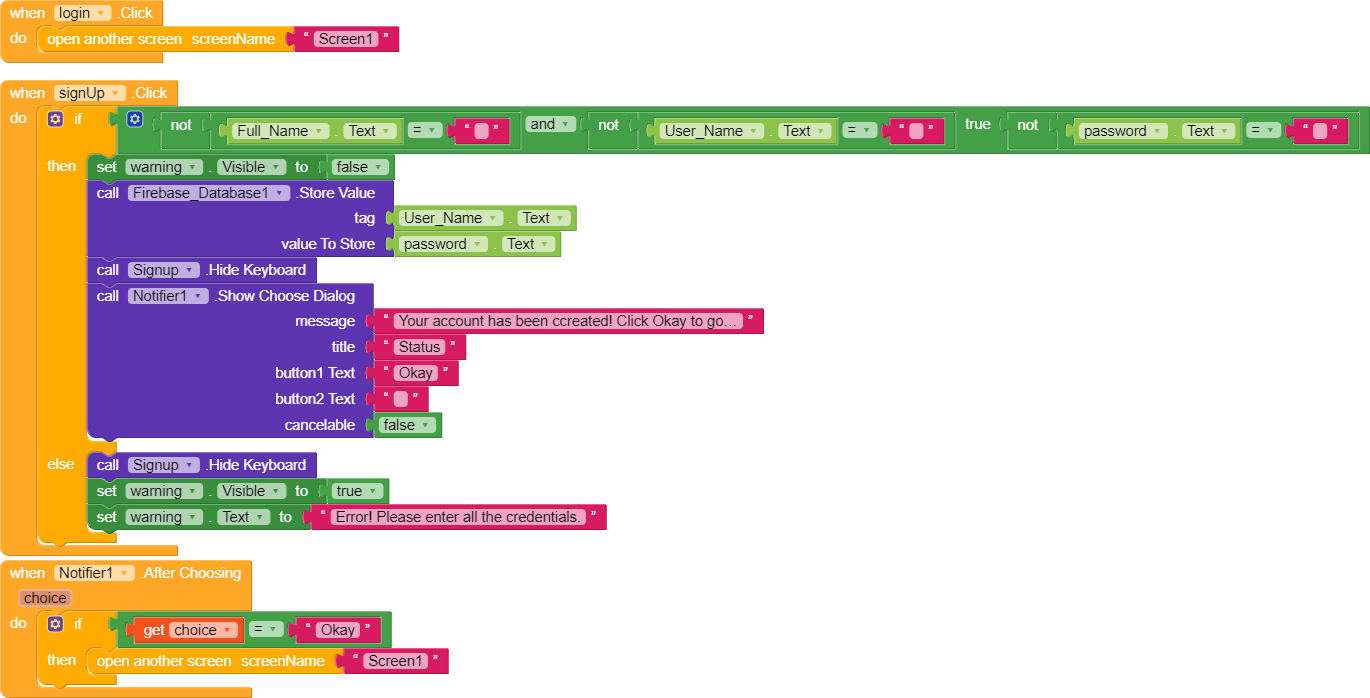


Figure B Sign Up screen

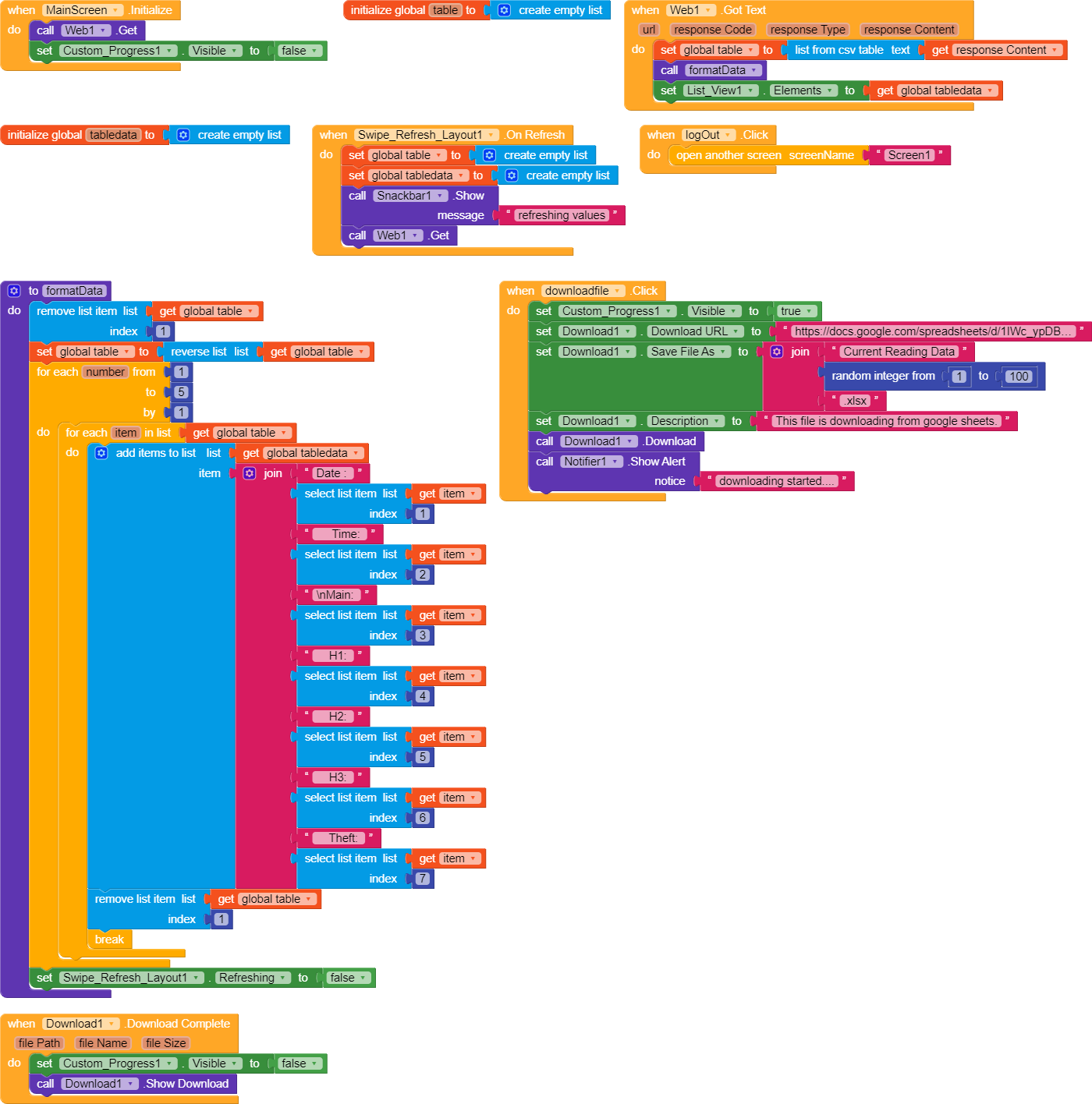


Figure C Main screen