Alexandria Engineering Journal 79 (2023) 44–55

Contents lists available at ScienceDirect

Alexandria Engineering Journal

journal homepage: www.elsevier.com/locate/aej

Original Article

Enhancing smart grids with a new IOT and cloud-based smart meter to predict the energy consumption with time series

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ARTICLE INFO

Keywords:
Smart grid
Smart meter
Energy balance
Power outage
Internet of things

ABSTRACT

More energy-consuming devices such as household electronics and more production facilities worldwide are causing increases in electricity demand and energy prices. The public service has difficulty maintaining the energy balance. These problems can be overcome by rapidly transforming the traditional electricity grid into a smart grid (SG) infrastructure. Smart meters (SMs) are an essential component of SGs and have vital tasks. This study has developed an Internet of Things (IoT) based SM that can reach high data rate of 38,400 bps or frequency of 160 MHz, using SQL Server for data storage and bidirectional data transmission with 174 W total load. In this way, consumers can track their energy consumption hourly, daily, and monthly, learn how much they spent on consumption, and receive warnings for a power outage. A fuzzy system and mobile application software are integrated into the SM structure for all these purposes. The designed device is believed to contribute significantly to the spread of SGs due to all these features.

1. Introduction

Smart grid (SG) is a new era of traditional power grid that employs many devices such as computers, sensors, various forms of communication technology and data analysis techniques to connect consumers and suppliers via bidirectional communication while improving system efficiency, reliability, security, flexibility and safety (Gharavi and Ghafurian [1]). However, SG installation would cost billions of dollars. According to the Electric Power Research Institute, a fully functional SG in the United States will cost between $338 billion and $476 billion (Garg and Dave [2]). In addition to the technical point of view, the rapid modernization of the world in recent years has increased electricity consumption and demand for SGs. Increasing emissions and climate change, energy supply security, and rising fuel prices have also required SGs to improve energy management globally (Obringer and Nateghi [3]).

Smart meters (SMs) are measuring devices and they perform many critical tasks such as recording data, two-sided data flow, controlling with other output devices. SMs have many applications and solutions in industries such as oil, water, heating as well as electricity (Ali et al. [4]; Slany et al. [5]; Lumbreras et al. [6]. Power generation control and power substation synchrophasors (Alavikia and Shabro [7]), residential smart metering systems including water and natural gas (Dashtar et al. [8]) be counted among the main application areas of SMs. They effectively benefit from communication, electrical-electronic and computer technologies in the successful completion of many operations such as recording, processing, and sending data.

A SM is one of the crucial components of SG infrastructure and affects dynamic electricity pricing (Zhou [9]). For deployment of smart meters the utilities have some functionality requirements of the smart meters. These minimum functionalities such as dynamic pricing, bidirectional communication, remote service, outage (fault detection) are set by local regulatory authorities (Barai et al. [10]). The SG is characterized by a two-way flow of information and electricity, and as this technology continues to advance and becomes more prevalent in day-to-day activity. The foundation of the SG's packet relaying is a two-way communication infrastructure, either wired or wireless (Abdalzaher et al. [11]).

Smart metering is a critical component of the SG that intelligently connects utility operators to the consumer and distribution domains. With an SM, consumers can have information about consumption data, baseline peak pricing, outage reports, energy efficient architectures (Ali Khan and Abbasi [12]), and remote meter management. The SM also allows utilities to track operational and security events and collect data

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https://doi.org/10.1016/j.aej.2023.07.071
Received 16 March 2023; Received in revised form 5 June 2023; Accepted 25 July 2023
Available online 7 August 2023

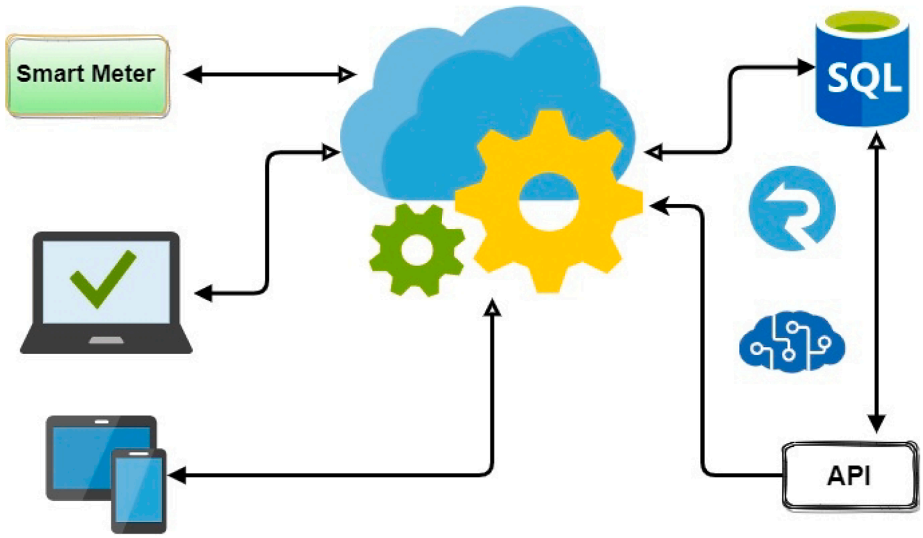


Fig. 1. The system architecture of the proposed SM.

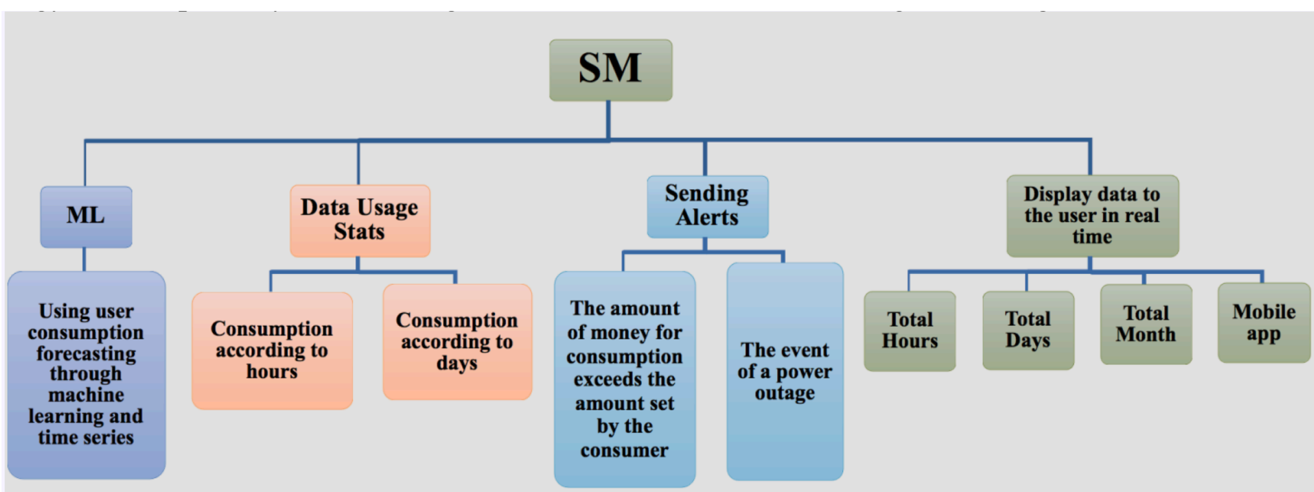
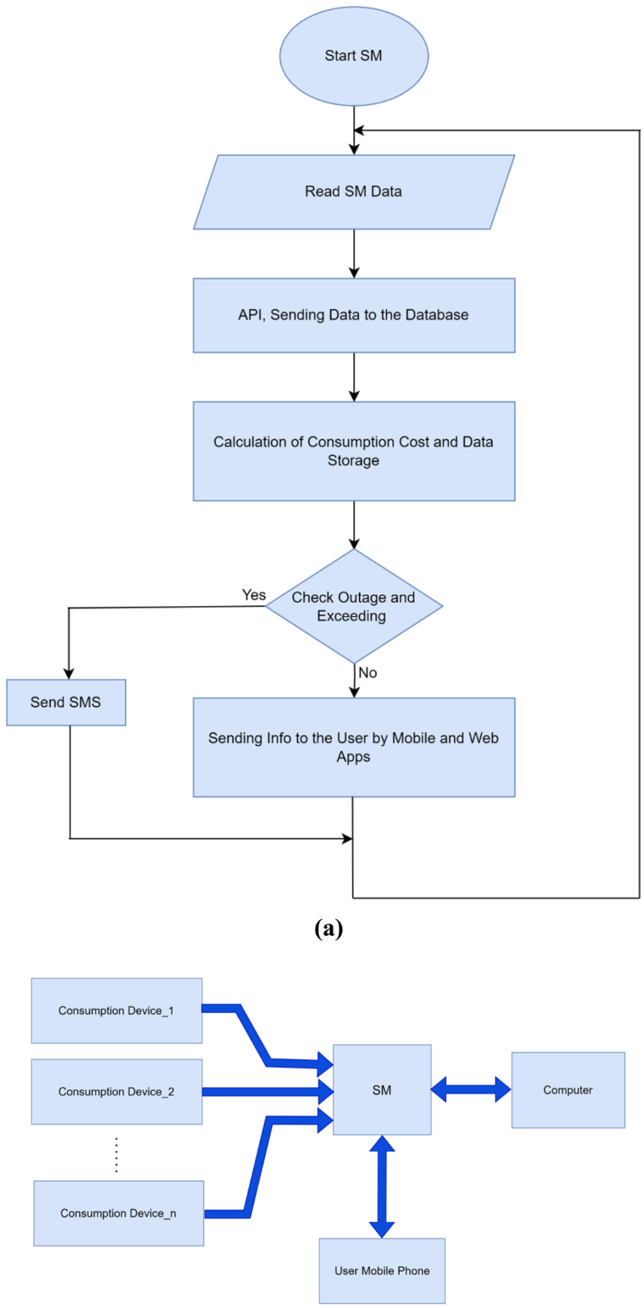


Fig. 2. SM Features of the proposed SM to rationalize energy consumption.

on power quality and load profile over a period of time (Guardrex [13]). Using an SM will aid in applying various approaches and algorithms to lower energy bills corresponding to time-of-use (TOU) tariffs set by the power utility and other limits. When TOU tariffs are combined with the adoption of appropriate control algorithms, consumer confidence in energy consumption increases, energy consumption and costs decrease, thereby improving technical indicators (Swahadika et al. [14]).

Residential energy use among current consumption units and its advanced metering infrastructure is an important concept (Glasgo et al. [15]). The use of SMs, especially in buildings, is vital, as buildings are one of the largest energy consumers, accounting for more than 40 % of total global energy consumption and emitting significant amounts of CO_2 (Rezaeimozafar et al. [16]). To ensure the reliability of the power supply, the increase in generation capacity, more resilient transmission and distribution infrastructure, and improved utility management can help decrease the private and social costs of unstable power. However, such upgrades come at a high cost that may be difficult to finance or create long-term sustainability issues (Meles et al. [17]). At the same time, only 5 %–8 % of Europe's installed generation capacity is used to handle load peaks, which occur only 1 % of the time. By reducing these peaks, savings can be made and the efficiency of the system can be increased (Khan and Jayaweera [18]). One of the solutions proposed in recent years is the installation of SMs for proactive energy use, energy theft reduction and load control in consumers' homes (Jaiswal and Thakre [19]).

SMs are related to the many aspects of the SG concept, such as monitoring the energy consumption with demand side load management in general and commercial buildings (Karthick and Chandrasekaran [20]; Klaić [21]), for distribution grid services and automation (Pau et al. [22]), for low voltage distribution systems in SG-based monitoring applications (Pandraju et al. [23]), Advanced Metering Infrastructure (AMI) data transmission method of SM in SG (Anupong et al. [24]), power quality issues for developing countries (Ahammed and Khan [25]), decentralized electricity storage (Römer et al. [26]), outage management of electric power distribution networks (He et al. [27]), secure cloud-based billing model (Mai and Khalil [28]), and evolution of SMs (Pandraju et al. [23]; Kabalci [29], Avancini et al. [30]). Besides these, many studies have been directly presented on the development of SMs in the literature. Jaiswal and Thakre [19] presented the mathematical modeling of a single-phase SM and calculated the active and reactive power components. Faisal et al. [31] has been made an energy cost analysis of an SM with a PIC series microprocessor. Kumar et al. [32] is designed an SM that needs separate circuit structures for current and voltage using the internet of things (IoT). Kabalci et al.



(a)

(b)

Fig. 3. (a) System data flow chart, (b) System energy flow.

[33] needs a mobile application interface to use widely. Abate et al. [34] has developed a low-cost SM for IoT and Govinda [35] gives the design of an SM with an Atmel microcontroller. A comparison of the developed SM and the previous ones will be given in the following sections.

This study presents the design and implementation of a new smart energy meter based on IoT. The designed SM in the study provides an interactive energy metering system that helps to measure the customer's electricity consumption and sends it to a database on an external server. The financial cost of consumption is calculated by corresponding to the usage time tariffs determined by the energy supplier company. Consumption and cost data are stored for the user on an hourly, daily and monthly basis. The system also provides a website and a mobile application that provide instant power consumption and cost data using SignalR technology (Microsoft [36]). Using the Twilio cloud application (Twilio [37]) in the system, a warning is sent to the user about the service interruption in the mobile application and phone via SMS.

2. Material and methods

The system architecture, all software and hardware components of the designed SM are given in Fig. 1. The system helps customers regulate their consumption behavior by giving them the opportunity to determine the cost of the proposed bill for the current month and calculate the percentage of their electricity expenditure. This is obtained by including the number of consumption expenditures in the amount of money specified for consumption by the user in the month, and by including the percentage of consumption time, including the number of consumption days, in the days of the month. If the percentage of expenses is increasing faster than the normal consumption time, a message about the imbalance is sent to the user, warning the customers that they need to regulate their consumption.

The proposed system uses artificial intelligence and machine learning (ML) to forecast consumption based on consumption data reflecting the user's daily, weekly and monthly behavior using the Microsoft ml.net library and time series in the forecasting process. The research tries to find a solution to rationalize energy consumption by constructing a SM with some characteristics given in Fig. 2.

According to the data flow chart in Fig. 3 (a), the SM data is transmitted to the database via API, and the consumption cost and the stored data are calculated. By this calculated consumption value, the user is informed that an outage will occur or whether the specified limit has been exceeded. Both mobile and web applications and SMS are used in these notifications. In Fig. 3 (b) system energy flow is presented.

2.1. Hardware

The schematic diagram and prototype of the developed SM are shown in Fig. 4. Contrary to similar designs, a single PZEM-004T module is used for the SM's current, voltage, and consumed energy amounts. This module is used as an electrical sensor to measure the consumed power. The module gives measured results in digital codes with a three-digit resolution via a universal asynchronous receiver/transmitter (UART) interface. The measured results are the voltage, current, power, and energy values having the units of volts, amperes, watts, and kilowatt-hours, respectively (Arenas et al. [38]). The Arduino receives the instantaneous data and accumulates it for a set period before sending it to SQL Server by API service via the internet and ESP8266.

ESP8266 Wi-Fi Module is a standalone microcontroller unit with integrated TCP/IP protocol stack that can give any microcontroller access to our Wi-Fi network. The ESP8266 can host an application or get all Wi-Fi network functions from another application processor. The ESP8266 module comes pre-programmed with an AT instruction set firmware, meaning we can connect it to the Arduino platform and get as much Wi-Fi capability as a Wi-Fi Shield offers. By connecting this module to the Wi-Fi network, we made the TCP/IP connections with Hayes style commands. So, we provided the data transfer possible over the Wi-Fi network in the environment where it is located.

As accumulation increases, the size of received data in the SQL Server will decrease. The DC buck converter steps down the DC voltage to 5 V. This value is also required to operate Arduino and PZEM-004T. A current transformer (CT) is used with PZEM when the load current is greater than 10 A. The current measurement range of PZEM without CT is 0–10 A; when using CT, it will be 0–100 A.

2.2. Application programming interface (API)

The IoT connects to the internet, continuously receiving and sending data. Sensors enable the interaction of the digital and physical worlds by collecting information that needs to be stored and processed. The data is processed on a remote server or cloud. API is a set of rules, orders, and protocols that contain standards regarded as an intermediary between

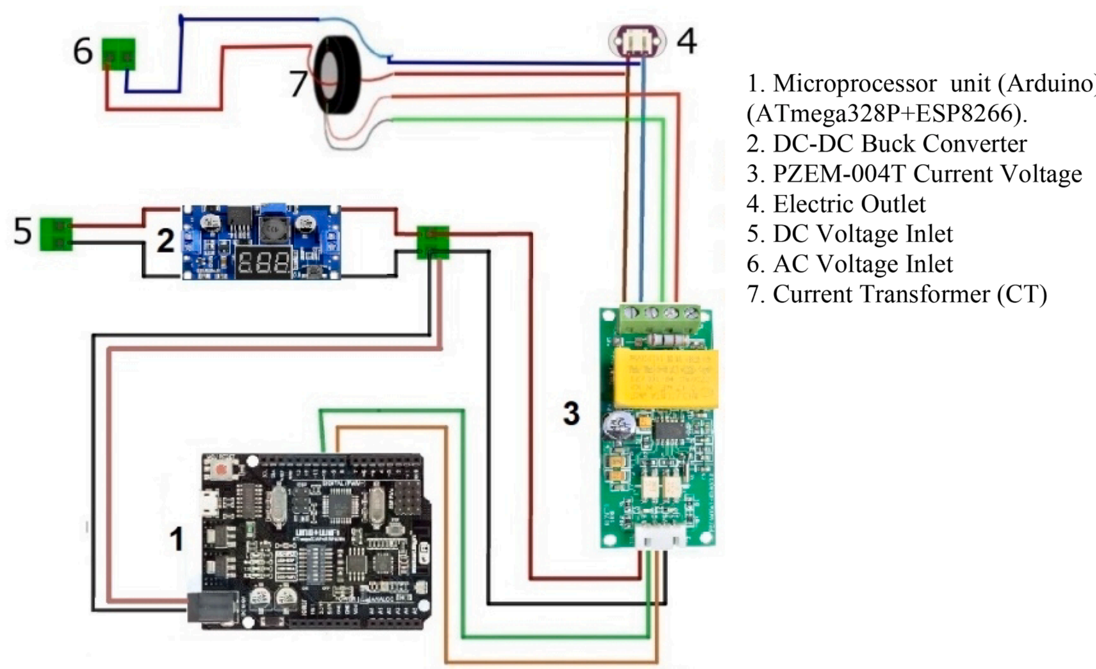


Fig. 4. Schematic diagram of the developed SM.

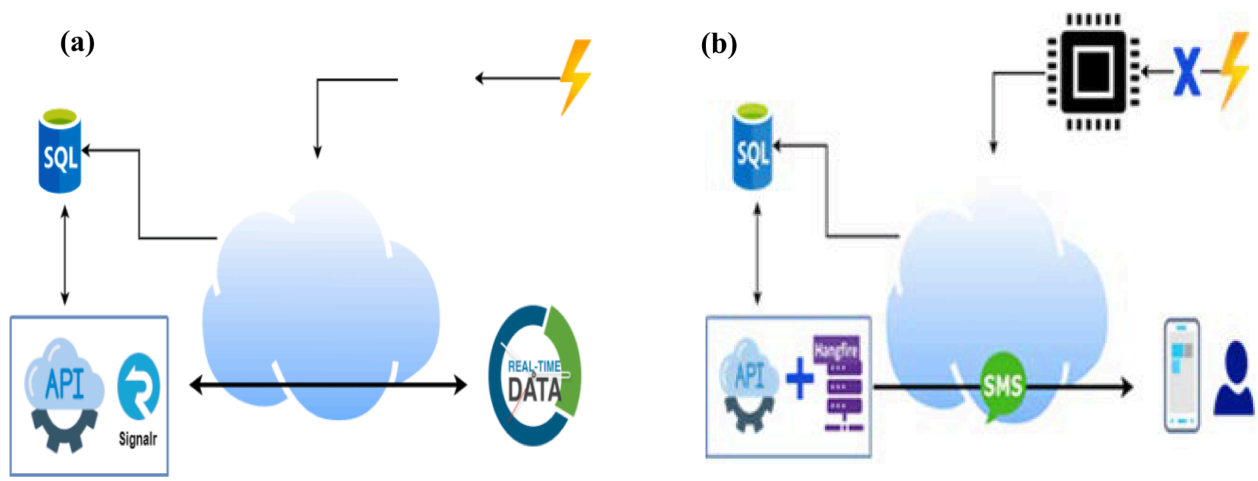


Fig. 5. (a) Conceptual architecture of the real-time system (b) Conceptual architecture of the notification system.

two interconnected operating systems and information exchange between the client and the server (Garg and Dave [2]). Microsoft's asp.net core API is used to transfer data to the database to protect it as the IoT connects to the API without knowing the database or its type. The API is responsible for transferring data to a database, which allows changing the type of database or cloud-stored in it without affecting the IoT. The data received to the API over the internet includes the consumed energy and the device number, and the data is sent to the SQL Server database for processing. The API provides the ability to instantly view data using Microsoft's SignalR library. This technology enables web and mobile applications to receive data instantly without the need to request data from the server.

As the electricity supply company determines the consumption prices and peak periods, the data is stored, processed and analyzed on an external server. In addition, the data stored on the external server is analyzed and the results are sent to the company and the user, and a connection is established between the company and the user. Both parties benefit from data and the ability to access data and send notifications from anywhere via the internet. These operations cannot be achieved if the data is only stored in the microcontroller.

2.2.1. ASP.NET core SignalR

API provides the ability to display data using Microsoft SignalR, an open-source library, instantly. This technology enables the web and mobile applications to receive data in real-time immediately and without requesting data from the server, enabling the user to view the current consumption data directly (Microsoft [36]). The conceptual architecture of the real-time system is given in Fig. 5a. The consumption data measured by the PZEM-004T is sent via a microcontroller to an external server. The microcontroller contains the API address of the website containing the Microsoft SignalR library and reads the data directly if the website stores the data in a database. The microcontroller also allows the user to learn the consumption amount directly in real time by sending it to the mobile application or website without any request.

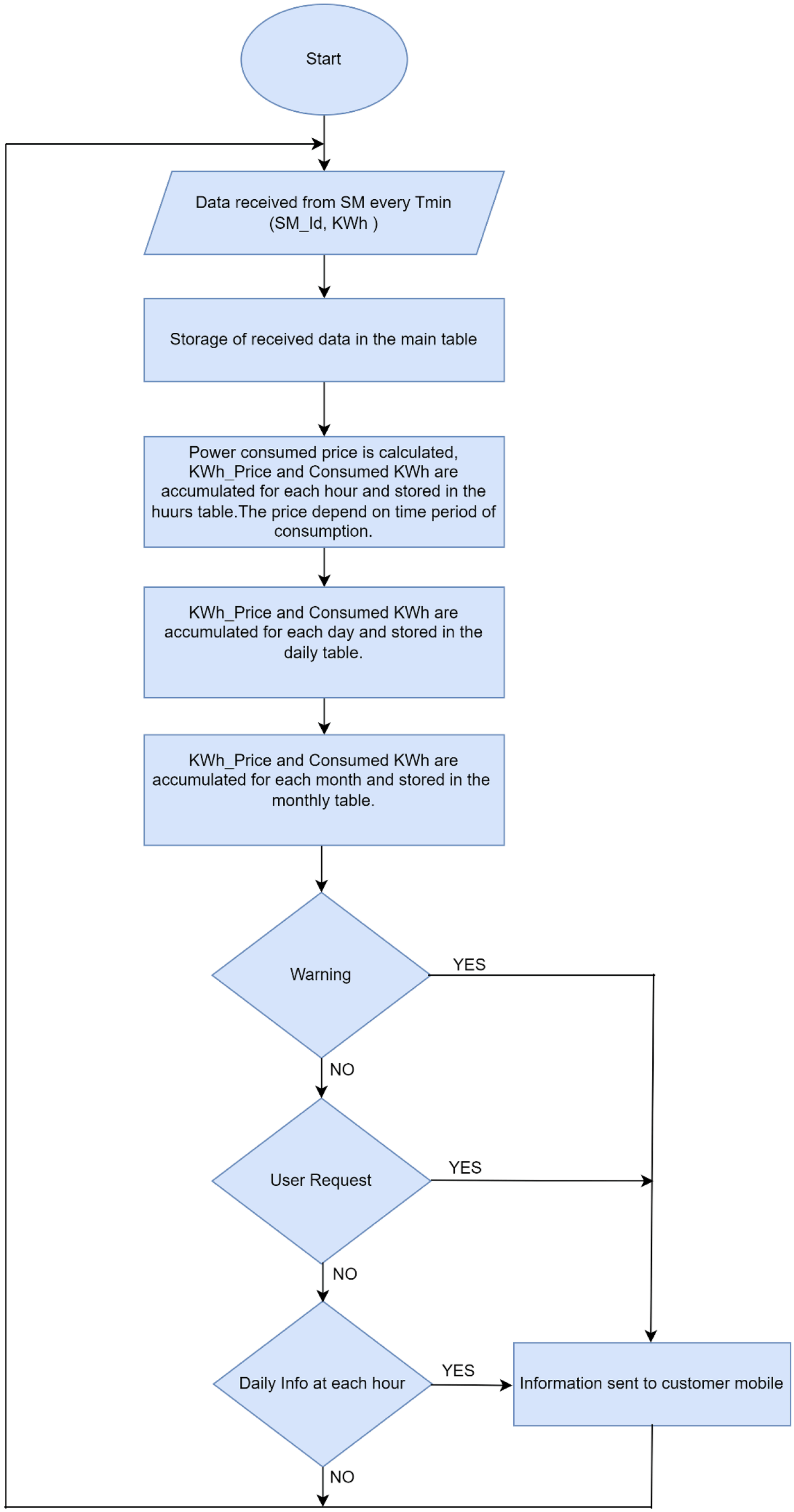


Fig. 6. Database flowchart.

Table 1
Main consumption data between Id 15 and 25.

Id	Device Id	KWh	Date_Time
15	10	0.014000002	2022-06-01 14:32:00
16	10	0.013000002	2022-06-01 14:37:00
17	10	0.009000001	2022-06-01 14:42:00
18	10	0.006000001	2022-06-01 14:47:00
19	10	0.008000001	2022-06-01 14:57:00
20	10	0.014000002	2022-06-01 15:02:00
21	10	0.014000002	2022-06-01 15:07:00
22	10	0.013000002	2022-06-01 15:16:00
23	10	0.014000002	2022-06-01 15:21:00
24	10	0.014000002	2022-06-01 15:26:00
25	10	0.013000002	2022-06-01 15:31:00

Table 2
Price table according to each period from a specific price.

Id	Period from	Period to	Price (£)
1	06:00:00	16:59:59	1.7
1004	17:00:00	21:59:59	2.49
1005	22:00:00	23:59:59	1.07
1006	00:00:00	05:59:59	1.07

Table 3
Hourly consumption data and price between Id 1 and Id 10.

Id	Device Id	Total (kWh)	Insert_Date	Price (£)
1	11	15	1.06.2022 13:00	25.500
2	10	0.086	1.06.2022 13:00	0.147
3	10	0.094	1.06.2022 14:00	0.159
4	10	0.108	1.06.2022 15:00	0.183
5	10	0.109	1.06.2022 16:00	0.187
6	10	0.102	1.06.2022 17:00	0.253
7	10	0.029	1.06.2022 18:00	0.072
8	10	0.022	1.06.2022 22:00	0.024
9	10	0.116	1.06.2022 23:00	0.122
10	10	0.086	1.06.2022 13:00	0.147

Table 4
Daily consumption data and price between Id 1 and Id 11.

Id	Device Id	Total (kWh)	Insert_Date	Price (£)
1	11	15	1.06.2022	25.5
2	10	0.666	1.06.2022	1.147
3	10	2.217	2.06.2022	3.584
4	10	2.331	3.06.2022	3.893
5	10	1.977	4.06.2022	3.439
6	10	2.215	5.06.2022	3.61
7	10	2.068	6.06.2022	3.296
8	10	2.022	7.06.2022	3.183
9	10	2.8	8.06.2022	4.891
10	10	1.703	9.06.2022	2.694
11	10	2.592	10.06.2022	4.424

Table 5
Monthly consumption data and price of devices Id 11 and Id 10.

Id	Device Id	Total (kWh)	Insert Date	Year Month	Price (£)
1	11	60.330	1.06.2022	2022_06	74.004
2	10	18.082	1.06.2022	2022_06	29.827

2.2.2. Hangfire

In the event of any failure in the electrical power supply, the user must be aware of this failure because the user is not always in the case using the website or mobile application. The system must monitor such failures and inform the user about them, and for that, the hangfire is used, a library used to conduct background processing of applications (Hangfire [39]). Hangfire has been added to the API to monitor the power supply status and notify the user about the outage. In addition, Hangfire was also used to send daily SMS messages to monitor and inform daily consumption in case the amount of money determined by the user for the current month is exceeded. Fig. 5b shows the conceptual architecture of the notification system in the developed SM. Power outages are detected every five minutes by monitoring the readings from the database from the microprocessor at regular intervals.

2.2.3. Forecasting by ml.net

Predicting energy consumption is the first step to conserving energy (Sah, [40]). In addition, since the system provides data on energy consumption for each user, it was necessary to exploit the existing data, which reflects the user's daily, weekly, and monthly energy consumption patterns. Since the user's urgent need is the amount of energy consumed, forecasting feature has been added using time series and Microsoft's open source framework, ml.net library. Prediction by the ml.net framework also provides security and inspection of the code using the singular spectrum analysis (SSA) algorithm (Microsoft [41]). Time series estimation was made using the SSA algorithm. The algorithm was trained by taking the value of the last 30 days and Microsoft's ml.net library was used to find the estimated value of the consumption amount for the next six days.

2.2.4. Singular spectrum analysis (SSA)

Singular spectrum analysis (SSA) is a technique analyzed by (Golyandina et al. [42]) and used by combining five segments in time series: Classical time series analysis, multivariate statistics, multivariate geometry, dynamical systems, and signal processing. SSA can be briefly explained with basic mathematical operations and formulas. It consists of decomposition and reconstruction stages. The decomposition is done by splitting into embedding and singular value decomposition steps.

Embedding Step

The trajectory matrix, $\mathbf{Y}$ is a Hankel matrix which is a lagged version of the original series of $\mathbf{y} = [y_1 \, . \, . \, . \, y_n]'$ and defined as Eq. (1) [42],

$$\mathbf{Y} = \begin{bmatrix} y_1 & y_2 & \cdots & y_\kappa \\ y_2 & y_3 & \cdots & y_{\kappa+1} \\ \vdots & \vdots & \ddots & \vdots \\ y_l & y_{l+1} & \cdots & y_{l+(\kappa-1)} \end{bmatrix}, \tag{1}$$

with $\kappa = n - l + 1$, each vector $\mathbf{y}_i = [y_i \ldots y_{l+(i-1)}]'$ is referred to as a window where l is the window length defined by the user. n is the length of real-valued time series.

Step of Singular Value Decomposition

The Eigenanalysis of $\mathbf{YY}'$ gives the eigenvalues $\lambda_1 \geq \cdots \geq \lambda_d$, where $d = rank(\mathbf{YY}')$ denoted by the corresponding left and right singular vectors, $\mathbf{w}_i$ and $\mathbf{v}_i$, respectively. Through the decomposition made in this step, Y can be obtained approximately through Eq. (2) [42],

$$\mathbf{Y} \approx \sum\nolimits_{i=1}^{d} \sqrt{\lambda_i}\mathbf{w}_i\mathbf{v}_i' \tag{2}$$

After the decomposition step, reconstruction can be applied as a second phase of the method, including grouping and diagonal averaging.

Grouping

This step selects the first m leading eigentriples associated with the signal and excludes the remaining (d-m) associated with the noise. So, in Eq. (3) [42], a proper selection of m is performed to disentangle Y into

$$\mathbf{Y} = \sum\nolimits_{i=1}^{m} \sqrt{\lambda_i}\mathbf{w}_i\mathbf{v}_i' + \varepsilon \tag{3}$$

Where ε is the error term representing the noise, the remainder of summands represents the signal. It is a readjustment method to select the number of principal components.

Diagonal Averaging

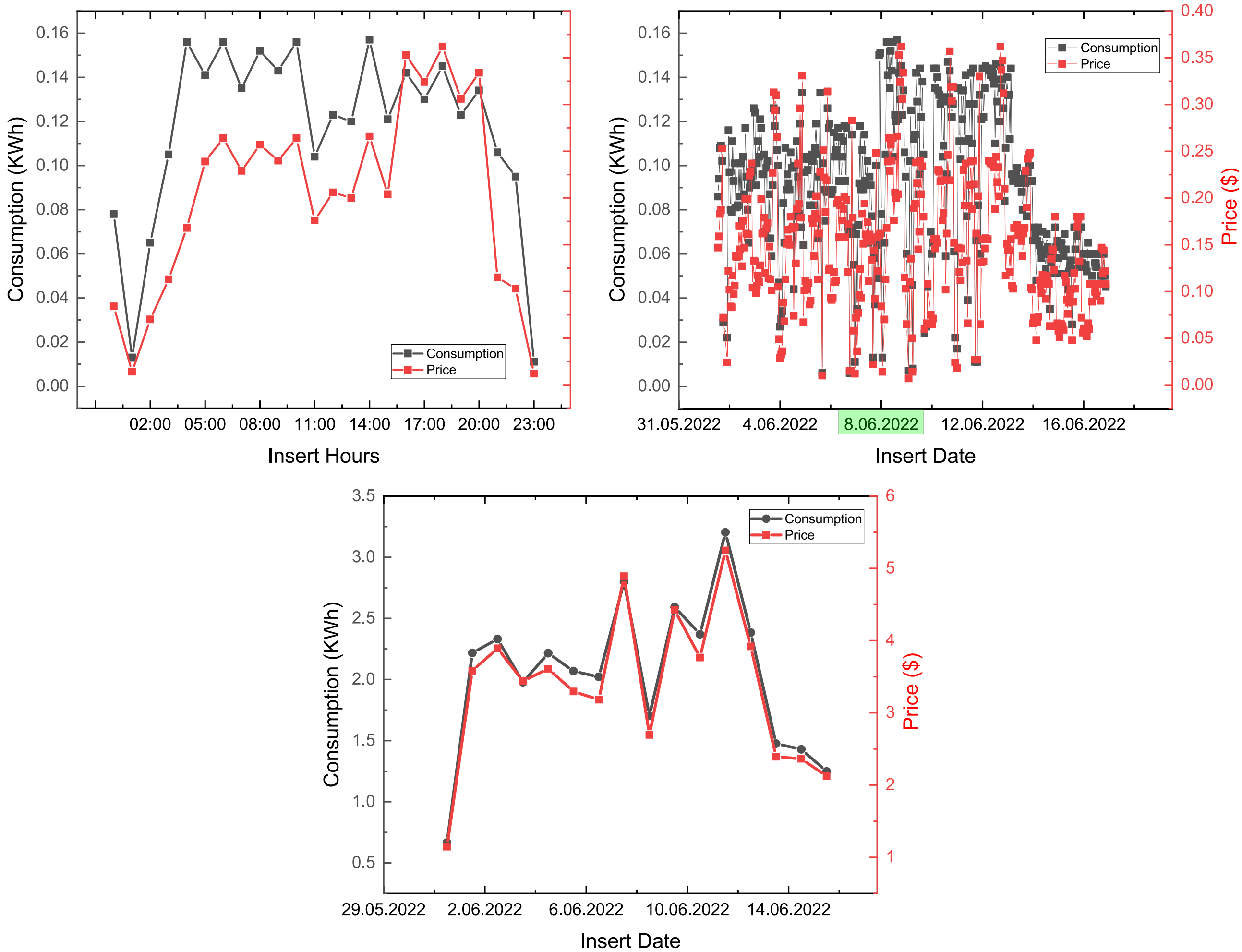


Fig. 7. (a) Hours, (b) days, (c) the eighth day.

In this step, the main idea is to reconstruct the series' deterministic component. The process is reversed so far, returning to a reconstructed variant of the trajectory matrix, the deterministic component of the series. An optimal way to do this is to average over all the elements of the several 'antidiagonals.' Formally, consider the linear space $\mathscr{M}_{l,\kappa}$ formed by the collection of all the $l \times \kappa$ matrices, let $\{\mathbf{h}_l\}_{l=1}^{n}$ vectors denote the canonical basis of $\mathbb{R}^n$ and consider the matrix $\mathbf{X} = [x_{i,j}] \in \mathscr{M}_{l\times\kappa}$. The mapping hence carries on the diagonal averaging procedure $\overline{\mathbb{D}} : \mathscr{M}_{l\times\kappa} \rightarrow \mathbb{R}^n$ defined as Eq. (4) [42],

$$\overline{\mathbb{D}}(\mathbf{X}) = \sum\nolimits_{w=2}^{\kappa+l} \mathbf{h}_{w-1} \sum_{(i,j)\in\mathscr{A}_w} \frac{x_{i,j}}{|\mathscr{A}_w|}, \tag{4}$$

Where $|\bullet|$ denotes the cardinal operator, $\mathscr{A}_w$ is the sum of indices to find the antidiagonal elements of $\mathbf{X}$ and defined as $\mathscr{A}_w = \{(i,j) : i+j = w\}$. Now, the deterministic component of y can be written as Eq. (5) [42],

$$\widetilde{\mathbf{y}} = \overline{\mathbb{D}}\left(\sum_{i\in I}\sqrt{\lambda_i \mathbf{w}_i \mathbf{v}_i^{'}}\right). \tag{5}$$

The decomposition gives the result of the SSA algorithm, but can be used when each subseries is classified as part of the trend or some periodic component or noise.

2.3. SQL server database

The received data is the device identifier, the accumulated power consumed, and the data date. The received data is first stored on the main screen. The trigger works directly while the data is stored. The energy consumption, calculated for T_{minute}, is multiplied by the energy price and collected in the hour table for one hour. The hours are aggregated and stored for each day in the daily schedule. Each day is grouped with the other day and stored in the monthly schedule for each device. The price depends on the time of consumption, and the day can be divided into three or more periods of "peak", "standard" and "off-peak". While the average price is in the standard period, the high price is at its peak and the low price is not at its peak. The flow of the obtained data is shown in Fig. 6.

2.4. User interface

The user interface is built using Microsoft's blazor web assembly asp.net core framework, a single page framework (SPA) for creating a client-side interactive web application using.net that works in all modern browsers, including mobile browsers (Swahadika et al. [14]). The web application provides consumption data for each user and the amount of money for consumption so that the user can view the data for each hour, day, or month. The site also displays consumption charts so the user can see the difference in consumption at the hour, day, and month levels. The data is displayed instantly using the SignalR library. Screenshots of

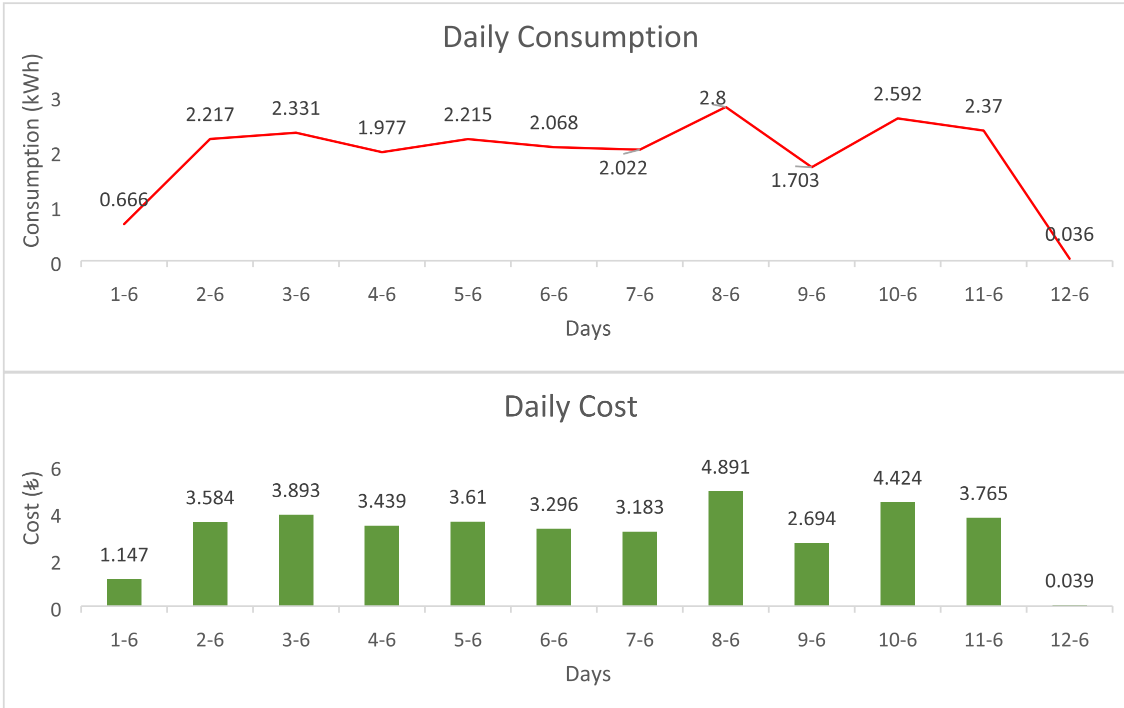
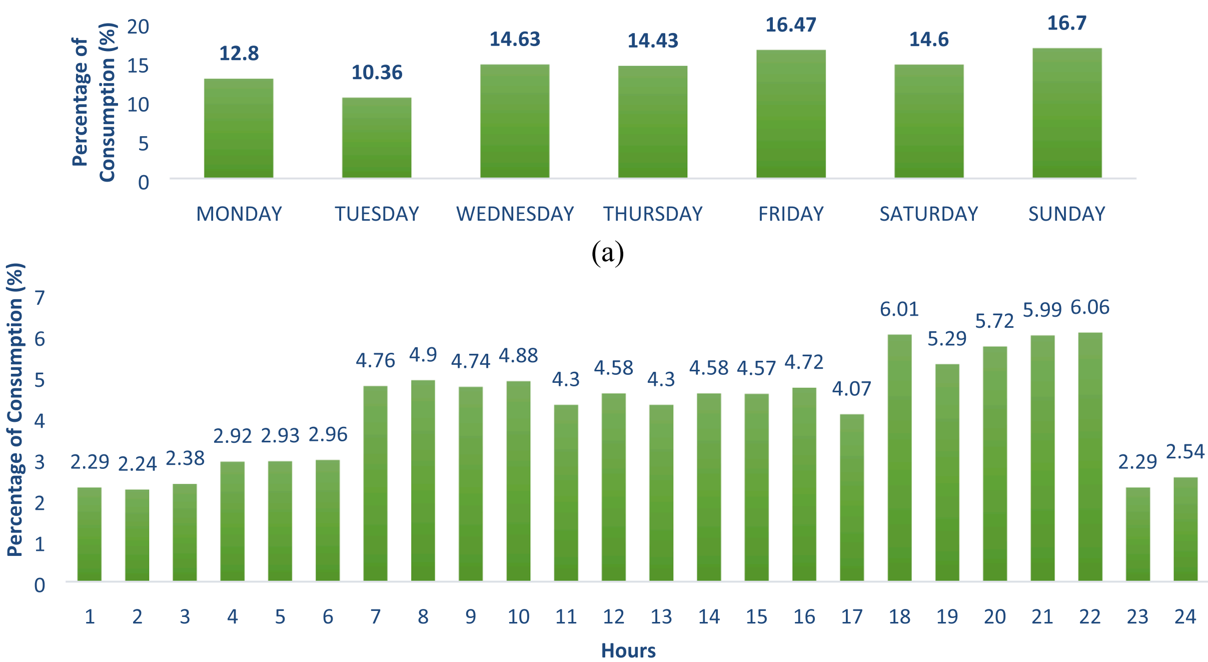


Fig. 8. Change in daily consumption and cost.



(b)

Fig. 9. Percentage of money for consumption by (a) days, (b) hours.

the realized user interfaces are given in Appendix B. The IoT is being applied to the lifestyles of all people in the world with the advancement of technology. Constantly, smartphones are used more and more, so it has become one of the crucial factors. Smartphone technology will connect the smart devices and people over the internet (Alexan et al. [43]). A mobile application was developed using Ionic framework technology, an open-source technology that facilitates the work of Android and iOS mobile applications easily and quickly. The application displays electrical energy consumption data in addition to the amounts consumed.

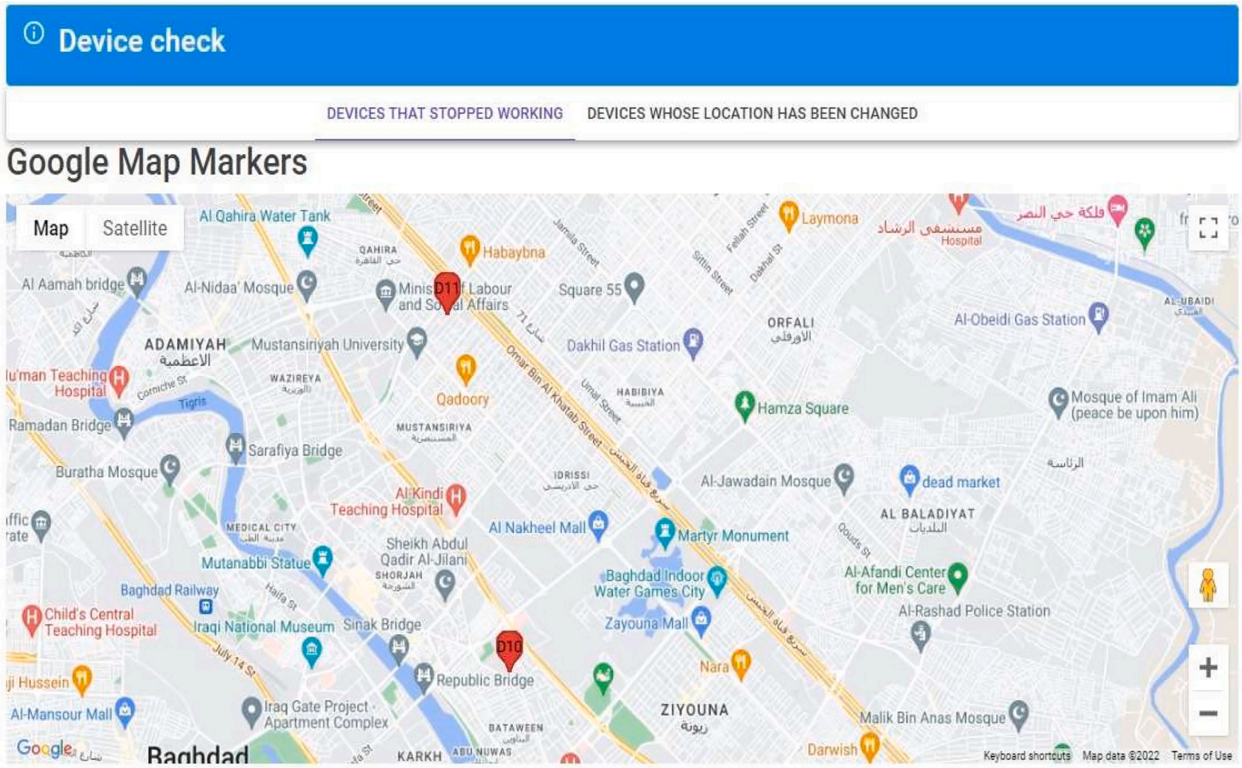


Fig. 10. Detection of the geographical location of the developed SM.

Table 6
Validation of the developed SM according the the consumptions.

SMs	Average Power (W)	Monthly Consumption (kWh)	Daily Consumption (kWh)
Ahammed and Khan [25]	296	126,9	4,23
Developed SM	174	78,412	2,613

3. Results and discussion

3.1. Data in SQL server

The SM data is given from the Tables 1–5 using Microsoft Word. A part of the data received from the SM and stored by the API in the SQL Server database is shown in Table 1. Data consisting of device ID, consumed energy and recording time in the database are received from the SM every 5 min. The device ID is the unique device number of each device, which is not repeated in the database for the purpose of storing the data of each device. Each house has its own device number and consumption is calculated for the house, not for each electrical appliance. Each consumption can then be tracked by associating the consumer's name and data with the device ID. The device number is finally linked to the user's name and address. Initially, two devices were used and then focused on a single device for the whole house. After receiving the data from more than one device at the same time, many consumption data were obtained and these data were distinguished by the device number.

Through the trigger, SQL Server calculates the consumption cost based on the price screen that determines the price of each period from a specific price, as in Table 2. The trigger logs data for each hour, day, and month in the hour, day, and month screens. Thus, consumption data can be used together with the financial cost of initial consumption on an hourly, daily, and monthly basis, as given in Tables 3–5, respectively. Screenshots in the database are also given in Appendix A.

The Origin drawing program was used to obtain all Fig. 7 graphics. Depending on the date change, the relationship between electrical energy consumption and price can be seen graphically from Fig. 7a and b. Fig. 7c shows this relationship more clearly for the eighth day.

3.2. Web application

An SM interface has been developed for users' security and registration to the system. After logging in, the user can access the consumption data for that month and the monetary consumption amount in addition to the percentage of the amount spent so far for that month by the user. Fig. 8 shows the change in the daily consumption and cost graphics. The system also contains a table of consumption and monetary amounts for the previous months to compare consumption between the months. The graphics in Figs. 8 and 9 were obtained using the Microsoft Excel. The screenshots of consumptions and costs in the web application are given in Appendix B.

Fig. 9a shows the percentage of monthly consumption amounts by days of the week, which allows the user to rationalize their energy consumption by selecting the days when the percentage of consumption is high. Fig. 9b shows the percentage of the amounts due for monthly consumption based on the hours of the day so that the users can determine the hours when the percentage of consumption is high, which helps them to rationalize energy consumption.

3.3. System SMS and mobile app

The system includes the feature of sending SMS to warn in case of a particular event. The first SMS sends a message to the user in case of a power outage. The second SMS concerns consumption limits. It occurs once a day and alerts the user to the occurrence of exceeding the specified consumption amount for that month so that the user can rationalize energy consumption to save money.

Users can benefit from mobile technology and web application advantages in the developed SM. The mobile application interface allows

Table 7
Comparison of the existing SMs by main features [19,25,32,33,44–50].

SMs	Alert in a power outage	Alert in case the amount is exceeded	User's consumption prices	Website to display the results to the user	Mobile app	View data in real-time	Consumption forecast	Geolocation
Jaiswal and Thakre [19]	No	No	No	No	No	No	No	No
Ahammed and Khan[25]	No	Yes	No	Yes	No	Yes	No	No
Kumar et. al. [32]	No	No	No	Yes	No	Yes	No	No
Kabalcı et. al. [33]	No	No	No	No	No	No	No	No
Minchala et. al. [44]	No	No	No	No	No	No	No	No
Aswin Raj et. al. [45]	No	Yes	No	No	No	No	No	No
Santhosh et. al. [46]	Yes	Yes	No	No	No	No	No	No
Fernando and Perera [47]	No	No	Yes	No	Yes	Yes	No	No
Sheeba et. al. [48]	No	No	Yes	Yes	Yes	Yes	No	No
Satriananda et. al. [49]	No	No	No	Yes	No	Yes	No	No
Salunkhe et. al. [50]	No	No	No	Yes	No	Yes	No	No
Developed SM	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The Green: The feature that exist in related reference, The Orange: The feature that doesn't exist in related reference.

the user to follow up on the consumption of electrical energy and the amounts incurred in consumption. Entry is done through the username and password. System SMS and mobile app screens are given in Appendix C.

3.4. Geolocation data

One of the problems electricity distribution companies face is the malfunctioning of electrical energy measuring devices. In such a case, information about the time of failure, the location of the measuring device, and whether the device has been moved or not is needed. The developed smart measurement system provides a solution to these problems as follows.

Geolocation of the device for locating the device in the event of a malfunction, the device's location data must be available, and the location data must be entered manually. This way, it is possible to know the device's location. However, tracking the device's location is impossible if transferred to another place. As adding a GPS Module to each SM is an expensive solution, alternatively, the device can be found by determining Geolocation with Google Maps, as in this study.

Showing stopped working devices: The devices that stopped sending data to the central database are searched, and in the case of a device that stopped sending data, the location of the device is displayed on the map, so the company can know the idle devices and locate them, which facilitates the process of directing maintenance address to repair the device. The location of the device is determined using the Google Maps geolocation feature. The request is sent through a microprocessor via the Internet, using an http request that contains an API key, through which the device is located using Google Maps geolocation technology. A value containing the device's longitude and latitude is received, then the value is sent to the external server and stored in the database. The device's location is then sent twice daily and compared to the value stored in the database. Thus, the devices stop sending data to determine their location and perform the necessary maintenance.

Displaying the devices whose location has been changed: The device's geographic location information is sent twice a day, the new geographic location is compared with the old geographic location, and in case of a difference, a change is sent to the company as a warning. Thus, the geographic location of the device has changed. The geolocation feature of the developed VM is shown in Fig. 10. From this feature, devices that have stopped working and devices that have been relocated can be easily detected.

3.5. Comparative study

Daily, weekly, and monthly consumption data for SM are only given in the reference [25]. According to our consumption, it can be computed that the [25] is 281 W. The difference is due to interruptions and irregularities in our electrical system. Table 6 gives the validation of our study according to the reference [25]. In our 174 W system the value of daily energy consumption is 2,613 kWh. Because of the electric outages in Iraq, our system is about 40 min active in an hour and average power consumption is 108 W. In this case, the rate of supplying electricity to the load is 62.06 %. This situation shows how important it is to detect a power outage in a SM.

The developed SM offers practical features that are more needed by the electricity sector and consumers to expand the use of SG infrastructure instead of features that are not commonly used and are not common. A comparison of the existing SMs, which includes the eight basic characteristics that SMs should have, is given in Table 7. It is seen that the developed SM has all these features.

4. Conclusions

This article introduces a new type of SM that includes all the required features for SMs to become widespread in SG infrastructure. These features are basic design with low-cost electronic components, API data storage in cloud-based SQL Server database, energy estimation and consumption on ml.net with SSA time series technique, user and utility interaction with IoT technology. In addition, the device is capable of detection of the geographical location for consumers and energy providers, and monitoring energy flow by a consumer-friendly mobile application.

The smartmeter has a data refresh rate every 5 min, a data rate of up to 38,400 bps, and 8 software features. The results are also confirmed in kWh with the literature. A monthly consumption value of 78.4 kWh was obtained for the two connected devices with a total 174 W consumption. Also, the rate of electrifying the load was found to be 62.06 %, which shows the importance of the SM to detect the power outage.

The developed device can monitor the energy consumed by customers, send consumption information to a database, display it to the user instantly via web and mobile applications, enable the user to determine the monetary amount of monthly consumption and track the amount spent. The device also warns the user if the total consumption amount exceeds the recommended monetary amount. Various charts allow the user to view the consumption amounts by months, days and hours of the day and to predict future consumption. The developed SM is recommended as a measurement infrastructure in SGs with unique enhanced features. For further studies, as the amount of data increases over time, the response time of the hardware and the delays in data transmission may vary, and this should be evaluated with longer-term data.

Declaration of Competing Interest

The authors thank for the financial support of Imam Ja'afar Al-Sadiq University, Department of Computer Technology, Engineering, College of Information Technology, Baghdad, Iraq, in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.aej.2023.07.071.

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