Smart Home Energy Management System Using Machine Learning

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Abstract

The cost and demand of energy are increasing day by day, leading the domain to find new and smart ways to monitor, control, and save energy. In the smart city, smart energy management systems help to resolve the energy management problem. Smart energy management systems cut the cost of energy in smart houses or buildings with their recommendations and predictions. This project proposed an architecture for a Home Energy Management System (HEMS), which collects real-time data; analyzes the patterns from the data, and further feed the patterns into the recommendation system to generate recommendations to save energy. A massive amount of data is collected using different sensors and machine learning algorithms are used to learn and identify user behavior's to achieve autonomous decision-making capabilities. Through the analysis, it can be seen that the solution greatly improves the humanization of the smart home system.

1.0 Problem Statement

In traditional method, the energy data are scattered and isolated across the facilities. Taking manual readings from energy meters is tedious and time-consuming. Lack of real-time visibility of energy/power consumption patterns. Excessive energy consumption due to unidentified equipment/devices inefficiencies. Lack of appropriate notification system for alerting personnel to take prompt action. Lack of performance monitoring system i.e., energy efficiency, specific energy consumption etc. Unavailability of high-frequency data, analytical tools, and historical data to understand and troubleshoot inefficiencies. Mostly no connectivity to process data. Energy Efficiency is related to operations efficiency an equipment performance. Manual Energy Balance, Data Validation and Reconciliation.

As the world grapples with the dual challenges of increasing energy demand and the urgent need to address environmental issues, the development of Smart Energy Management Systems (SEMS) has emerged as a critical solution. These systems are designed to intelligently control and optimize energy resources, ensuring that energy is generated, distributed, and consumed in the most efficient and sustainable manner possible. At the heart of this transformation lies Machine Learning (ML), a powerful tool that enables SEMS to make data-driven decisions, predict energy demand, and respond to changing conditions in real-time. One of the key applications of ML in SEMS is demand forecasting. ML algorithms analyze vast amounts of historical energy consumption data, weather patterns, and real-time information to predict future energy demand with remarkable accuracy. This capability allows utilities and energy providers to adjust their generation and distribution strategies dynamically, reducing energy wastage and operational costs.

In this project, My Product idea is to create a Smart Energy app, which help the customers to

- Prioritize energy efficiency initiatives.
- Remote load management for central control. Load management can be done by a central monitoring team or through the built-in scheduler.
- Understand power quality issues. This system can help detect vital power quality issues. It gives insights into the total harmonic distortion from under-voltages, over-voltages, and power outages. There are built-in alarms that can detect power quality problems.
- Visualization and Monitoring-This app presents the energy data in an easy to understand format
- Cost estimation and Budgeting- set budgets and receive alerts when consumption exceeds limits
- Personalized recommendations-get suggestions on energy saving measures and behavioral changes.

2.**0 Market/Customer/Business need Assessment**

2.1 Market need assessment: market need assessment for smart home energy management systems (HEMS):

Market Drivers

* Growing emphasis on energy efficiency and sustainability
* Rising energy costs
* Increasing adoption of smart home devices
* Technological advancements in sensors and data analytics

Market Needs

* Cost-effective solutions: Consumers are looking for HEMS that are affordable to install and operate.
* User-friendly interfaces: HEMS should be easy to use and understand, even for non-tech-savvy consumers.
* Seamless integration: HEMS should integrate seamlessly with existing smart home devices and appliances.
* Security and privacy: Consumers are concerned about the security of their data and privacy. HEMS should have robust security features.
* Real-time data and insights: HEMS should provide real-time data on energy consumption and insights into how to save energy.
* Automated controls: HEMS should automate energy-saving measures, such as adjusting thermostats or turning off lights when not in use.

Overall, there is a strong market need for smart home energy management systems that are affordable, user-friendly, and effective in helping consumers save energy and money.

2.2 Customer needs assessment:

Conducting a customer need assessment for a smart home energy management system (HEMS) is crucial to understanding the target market and developing a successful product. Here are some key areas to explore:

Needs:

* Cost savings: Assess how much customers prioritize saving money on their energy bills.
* Energy monitoring: Gauge interest in tracking and analyzing energy consumption patterns.
* Sustainability: Understand how important environmental responsibility is to potential customers.
* Convenience and automation: Evaluate interest in features that automatically adjust energy use for optimal efficiency.

Challenges:

* Price sensitivity: Identify the price range that would be most acceptable to customers.
* Technical knowledge: Assess how comfortable customers are with smart home technology.
* Data privacy concerns: Understand how important data security and privacy are to potential customers.

Overall, a customer need assessment will help you develop a smart home EMS that meets the needs and expectations of your target market.

2.3 Business needs assessment:

A smart home energy management system (HEMS) can offer significant benefits to both businesses and consumers. Here's a breakdown of the business needs assessment for a smart home EMS:

Benefits for Businesses

* Increased customer engagement: HEMS can provide valuable data on customer energy usage patterns, allowing businesses to offer targeted energy-saving programs and promotions.
* Improved grid management: By encouraging off-peak energy use and optimizing home energy consumption, HEMS can contribute to a more stable and efficient electricity grid.
* New revenue streams: Businesses can develop new revenue streams by offering HEMS as a value-added service or selling data insights to third parties (with customer consent).

Benefits for Consumers

* Reduced energy costs: HEMS empowers consumers to gain insights into their energy consumption and identify areas for savings.
* Increased comfort and convenience: HEMS allows for automation of heating, cooling, and other appliances, leading to a more comfortable and convenient living experience.
* Environmental benefits: Reduced energy consumption through HEMS translates to a lower environmental impact.

Overall, a smart home EMS presents a compelling opportunity for businesses to improve customer engagement, optimize grid management, and generate new revenue streams. By empowering consumers to manage their energy use more effectively, HEMS can contribute to a more sustainable future.

3.0 **Target Specifications and characteristics**

- Monitoring: The system should be able to monitor real-time and historical energy consumption data from various sources in the home, including smart meters, appliances, and lighting.
- Control: The system should allow users to remotely control smart home devices to optimize energy use. This could include adjusting thermostats, scheduling appliance operation, and turning lights on or off.
- Automation: The system should be able to automate energy-saving actions based on user preferences and real-time energy usage data. For example, it could automatically adjust thermostats when nobody is home or turn off lights in unoccupied rooms.
- Reporting: The system should provide users with reports on their energy consumption patterns and identify areas where they can save energy.
- Security: The system should be secure and protect user data from cyber-attacks.

3.1 **Performance Requirements**

The performance requirements of a smart home energy management system (EMS) can be broadly categorized into three areas:

* Data Acquisition and Processing: The system should be able to collect data from various sensors and smart devices in the home efficiently. This includes real-time energy consumption data, appliance status, and environmental conditions. The system should also be able to process this data quickly and accurately to generate insights and make control decisions.

* Communication and Connectivity: The EMS should have reliable communication protocols to ensure seamless data exchange between different devices and the central hub. This includes compatibility with various smart home device standards and protocols.

* Security and Privacy: The system should be designed with robust security measures to protect user data and prevent unauthorized access. This includes encryption of sensitive information and secure authentication protocols.

4.**0 External Search**

A complete external search was done to obtain insights and knowledge for Smart Energy development in smart homes, industries, offices etc.

Online sources, academic journals, market reports, and industrial databases were researched. The purpose was to investigate latest technology trends, consumer behavior's, technological advances

4.1 Online resources

Science Direct: Researchers have focused on how to deal with unnecessary energy consumption .This study explores the top 10 SHEMs available in the market today

Wiley Online Library (journal of sensors): gives a study of the design of the project

Research gate journal papers.

YouTube channels

6.0 **Applicable Patents**

US Patent No. 6,178,362 describes an energy management system and method that uses machine learning to optimize energy consumption in a building. The system can collect data on energy use from various sources, such as sensors and meters, and then use machine learning algorithms to identify patterns and trends in energy consumption. This information can then be used to develop strategies for reducing energy use.

* US Patent No. 8,024,073 discloses a system for managing energy consumption in a home or business. The system includes a smart meter that collects data on energy use, as well as a machine learning module that analyzes the data and identifies opportunities to reduce energy consumption. The system can then automatically adjust energy-consuming devices, such as thermostats and lighting systems, to reduce energy use.

* US Patent No. 11,594,912 relates to a smart energy management system for a self-sufficient solar home. The system uses machine learning to control the operation of household appliances based on the state of charge of a battery storage device. This helps to ensure that the home has sufficient power during times when solar energy is not available.

7.0 Applicable Constraints and Regulations

Regulations and constraints on smart energy management systems (SEMS) using machine learning can be categorized into three main areas:

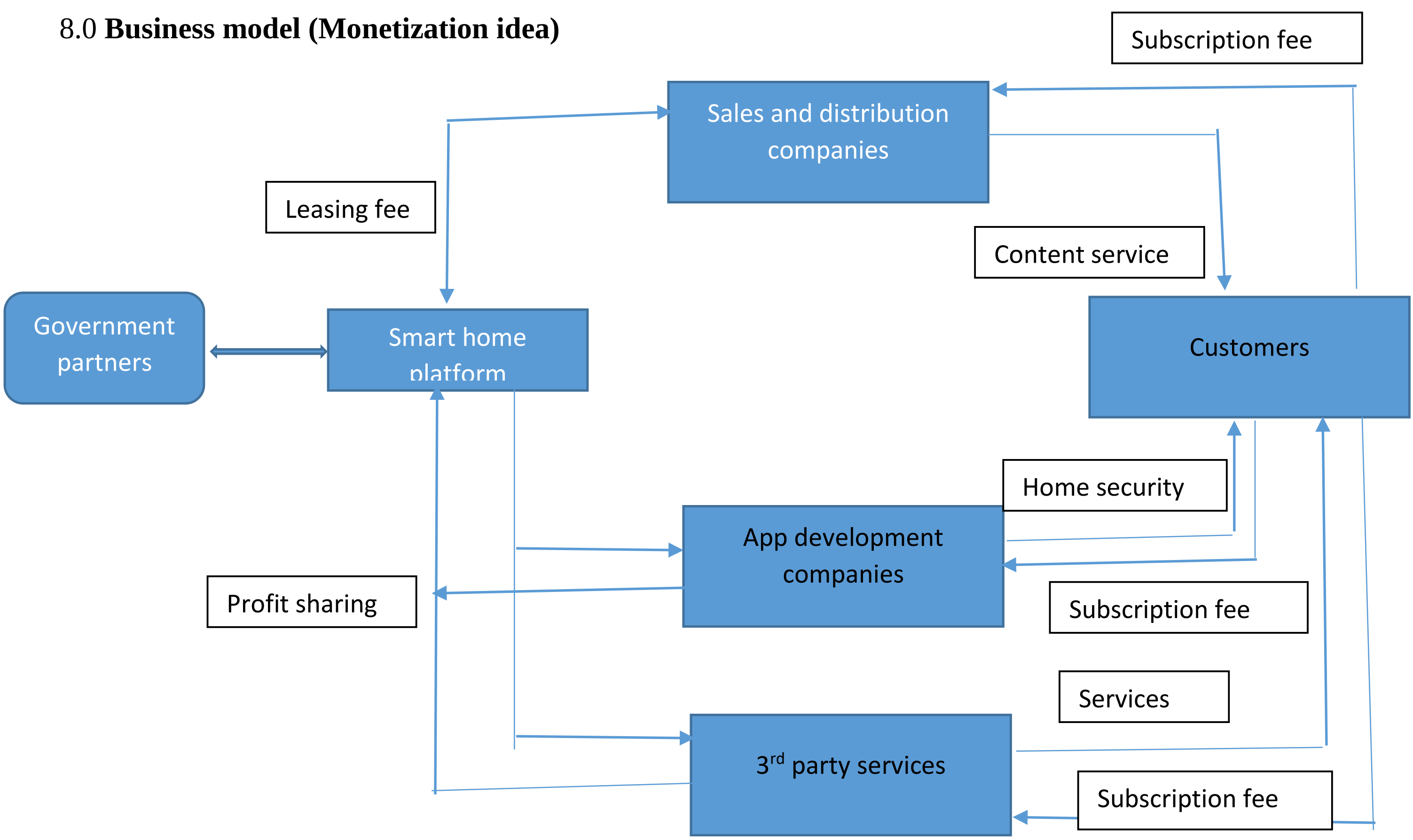
* Data privacy and security: As SEMS collect energy consumption data from users, regulations around data privacy and security are crucial. These regulations may include requirements for anonymizing data, implementing strong cyber security measures, and obtaining user consent for data collection and use.

* Grid stability and reliability: SEMS should not compromise the stability and reliability of the power grid. Regulations may address how SEMS interact with the grid, including managing peak demand and ensuring power quality.

* Fairness and transparency: Machine learning models used in SEMS should be fair and transparent. This means avoiding models that discriminate against certain users or that are not explainable.

Specific regulations will vary depending on the region, but these are some of the key considerations for developers of SEMS using machine learning.

8.0 **Business model (Monetization idea)**



Subscription Model: Charge a recurring fee for access to the system's features, such as real-time energy consumption monitoring, historical data analysis, and personalized energy-saving recommendations. This model provides a predictable revenue stream and incentivizes ongoing engagement.

 * Pay-Per-Use Model: Charge users based on the amount of energy they save through the system's recommendations. This model aligns your incentives with those of your customers and encourages them to maximize their energy savings.

 * Data Insights Model: Sell anonymized energy consumption data to utility companies and other businesses. This data can be valuable for understanding customer behavior, developing targeted energy-saving programs, and improving grid efficiency.

 * Hardware Sales Model: In addition to the software platform, you can sell the hardware components that connect to smart meters and appliances. This can be a one-time fee or bundled with a subscription plan.

We can achieve a good customers by

Customer Segments:

We divide the potential customers in our target market into two segments. The first early adopter segment comprising about 30% of the target customer base, are more likely to pay explicit attention to the rate selection problem. The remaining 70%, who comprise the second mass market segment, are less likely to actively seek our solution. The early adopter segment is comprised of households that can be categorized as one or more of:

• Greens: Defined as households interested in energy efficiency in their homes, this number is as high as 47%. The number is growing steadily as awareness of efficiency opportunities increases.
• Techies: Defined as technophile consumers eager and willing to try new products, this number is at 29% of the population.

• Prosumers: Defined as homeowners that have solar panels, electric cars, pool pumps, and other appliances that make them more sensitive to their electricity rates, this segment is currently at about 20% of homeowners and is growing rapidly.

Distribution Channels: We are pursuing two sales channels, one direct and one indirect:

 1. The direct sales channel is driven by the web and mobile applications, where customers subscribe to our service annually by paying through an online financial transaction.

2. The indirect sales channel bundles our services with home energy management systems (HEMS), such that we are compensated on a per-installation basis or bulk basis by the HEMS vendors.

Customer Development: The cost of customer acquisition is a critical variable in our business model. We will initially conduct experiments with various marketing channels to evaluate that cost for each channel. We will use the experimental results to select a subset to pursue aggressively as we scale our customer base. Our initial focus is on the following:

(1) Customer Referrals: Early adopters of our services will refer additional customers in exchange for substantial discounts on their subscription fees.

(2) Social Media and Advertising: We will offer some free web-based rate evaluation functionality, so we can attract potential customers to "try before they buy" using various social media outlets and targeted advertising online (Google, Facebook) .

(3) Marketing Partnerships: We are in the process of developing marketing partnerships with energy management vendors who already have a footprint in our potential customers' homes, to include our service as part of a larger platform.

(4) Viral Marketing: We will launch campaigns that encourage social venues like yoga studios and coffee shops

(5) Utility Partnerships: We will also approach the PUCs and utilities to have our service mentioned on utility bills and their websites as a resource available to consumers.

10.0 **Concept generation**

The main aim of this project is to develop SHEMS that can optimize energy usage by homeowner using electricity grid supply and home appliances.

Based on the preferences of the user and avaibility of energy resources, the system should be able to monitor, control and manage the amount of energy used in real time.

11.0 **Concept Development**

Smart home energy management systems have been identified as an effective solution to

Reduce energy consumption and cost in residential areas. The integration of Internet of

Things (IoT) and machine learning techniques in smart home energy management systems

Can enhance the system's performance and efficiency. This Product idea aims to

Investigate the design and implementation of a smart home energy management system using IoT and machine learning

With the increasing demand for sustainable energy usage, the design and implementation of

Smart home energy management systems have become a need. The

Integration of Internet of Things (IoT) and machine learning techniques in these systems

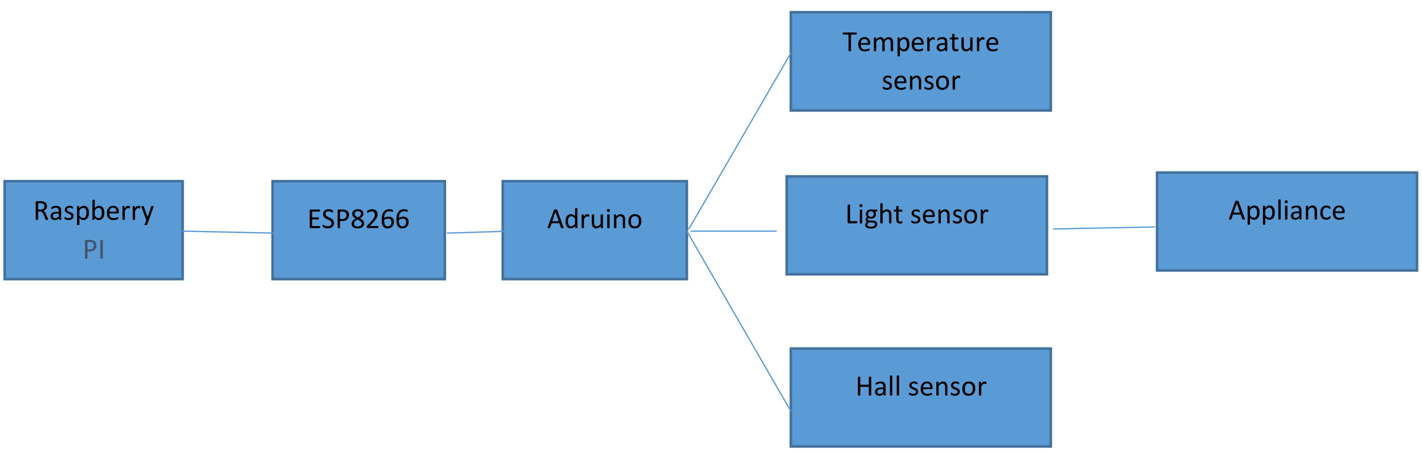
Has opened up new possibilities for managing energy consumption and reducing costs.

Smart home energy management system can learn from the residents' energy usage patterns

And adjust energy consumption to reduce waste and unnecessary expenditure. This

Aims to investigate the design and implementation of a smart home energy

Management system using IoT and machine learning.

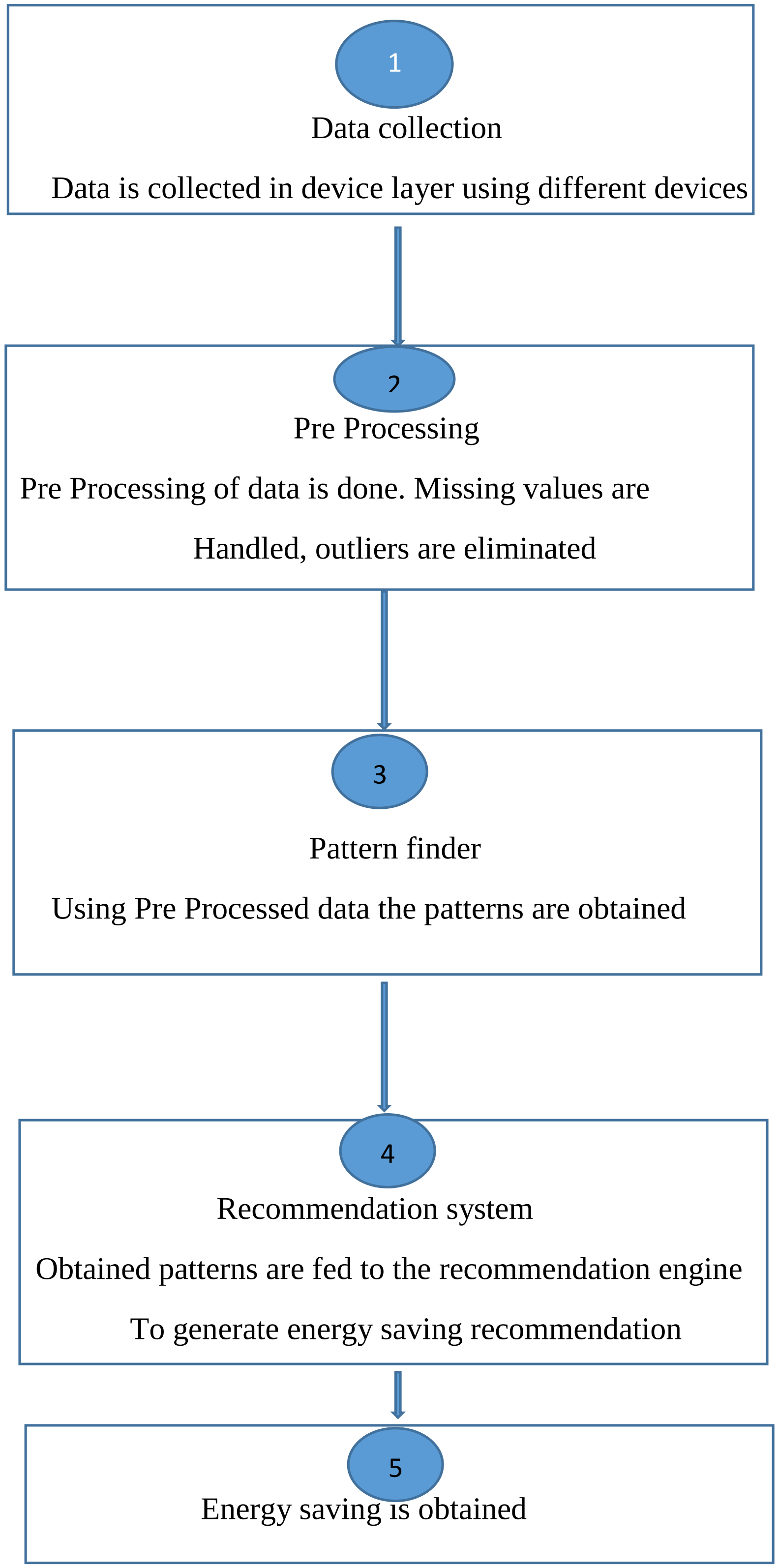


12.0 F**inal Product Prototype (abstract) with schematic diagram**

Abstract

The effective use of energy in smart homes saves money, improves sustainability, and decreases the carbon impact on a wide scale. The vast volume of data generated throughout a nation poses several data storage, management, and analysis issues. IoT and Big Data are logical solutions to these problems. IoT technologies may offer a ubiquitous computing platform for sensing, monitoring, and controlling the energy use of home appliances on a wide scale. This information is gathered utilizing a variety of wireless sensors put in residential units. Big Data technology may be used to collect simultaneously and analyze the data. Data is gathered, evaluated, and translated into usable information in reports, graphs, and charts that utilize predictive analytics and sophisticated technologies. HEMS is a critical component of the smart grid environment because it enables load management among homeowners to reduce energy costs while flexibly supporting high penetration Renewable Energy Sources at both the distant and local levels. Traditional household appliances, as well as developing ones such as Energy Storage Systems (ESS), Electrical Vehicles (EV), and others, must be considered in an efficient and cost-effective HEMS. The new appliances allow the HEMS to reduce costs, even more, minimize peak pressures, and overcome the volatility of RES production. Unmanaged EV charging and discharging, for example, might increase the peak demand, lead to dangerous overload, and damage local distribution lines. To reduce the user's power cost and discontent, a convex programming home energy optimization framework including schedule-based appliances, battery-assisted appliances, and model-based appliances is proposed

12.1 **Process flow diagram**



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The proposed architecture of HEMS collects real-time data. The collected data is being used for further analysis. The patterns of energy consumption are being analyzed using ML techniques in the administration layers of the proposed architecture. These observed patterns are further fed into the recommendation system in the service layer

Process flow diagram of the proposed work Following steps are carried out for proposed work.

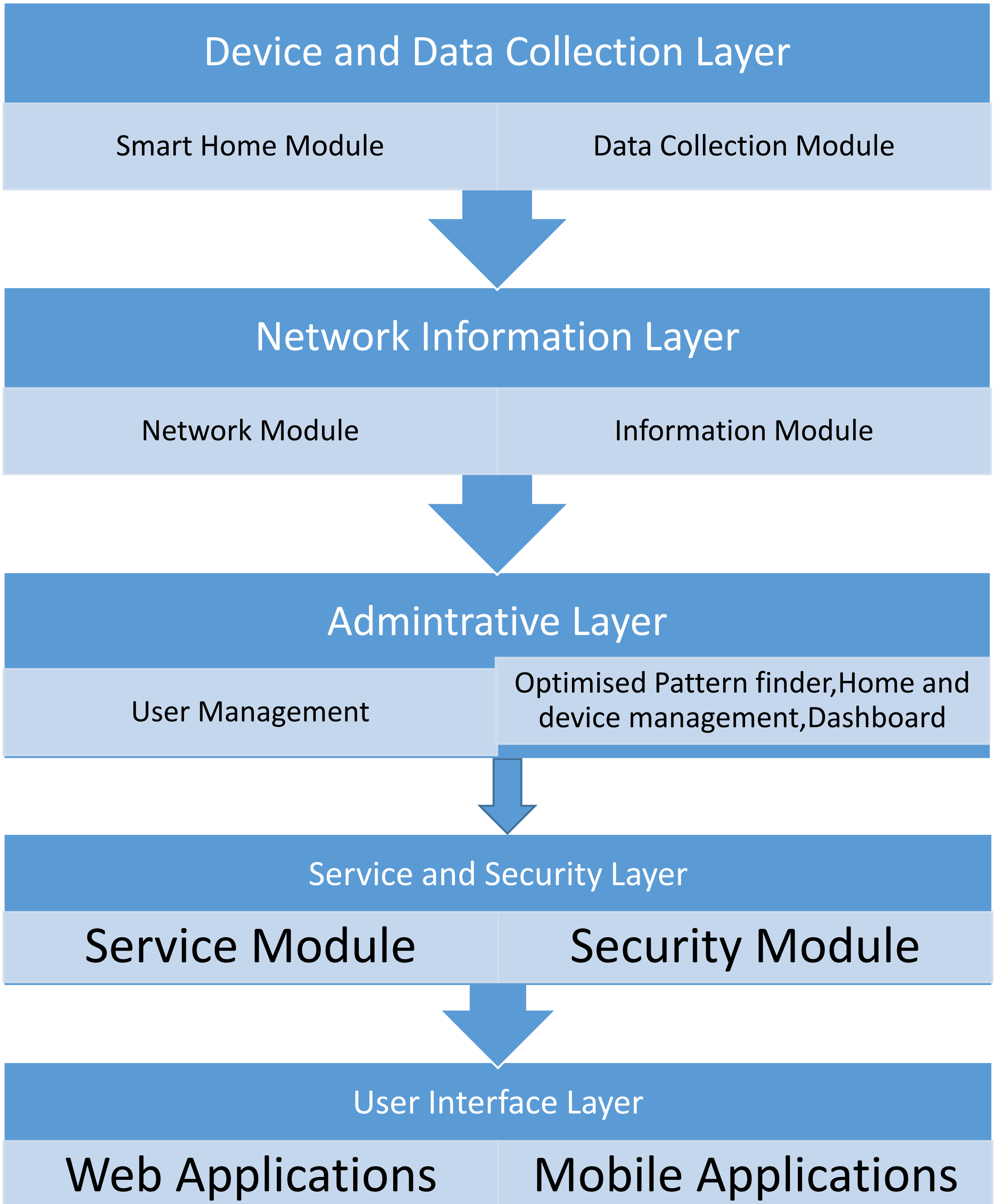
Step 1: Data is collected in the device layer using different devices like sensors, controllers, actuators, gateways, etc.

Step 2: Preprocessing of the collected data is being done using different ML techniques.

Step 3: Using the preprocessed data obtained in step 2, the patterns of the energy consumption are obtained and different parameters which affect the energy consumption patterns are also analyzed.

Step 4: The patterns obtained in step 3 are fed into the recommendation system to generate the recommendations which can help to save energy. Step 5: With the help of a pattern finder and the recommendation system in steps 3 and 4, energy-saving recommendations are being generated which helps in saving energy

12.2 **Proposed Architecture of Home Energy Management System**



Device Layer

This layer is divided into two sub-modules i.e., Smart home which consists of different types of devices in the smart home, and Data collection which contains different data collection devices.

Smart Home Module HEMS is used to optimize the operating time of household appliances. HEMS makes the consumer's life easier by lowering electricity degeneracy and expense. Appliances are divided into three groups for optimization: shift able, non-shift able, and fixed appliances.

Data Collection Module IoT component gateways, sensors, actuators, and controllers permits data collection from numerous household appliances. The device layer also controls actuators and home automation devices.

Network and Information Layer

This layer is divided into two sub-modules i.e., network module and the information module. Network Module to choose the communication protocols for each home device, this layer evaluates components such as a collection of sensors, HTTP and TCP/IP, Bluetooth, WiFi, and 4G communication. The communication layer allows other levels in the architecture to communicate with one another. The HEMS communication layer utilizes Zigbee, TCP/IP, HTTP/IP, Bluetooth, WiFi, and other protocols/technologies.

Information Module

The information produced in the device layer is saved in this layer. The information layer, in particular, uses modules to handle five categories of data: user profile, device profile, sensor data, service data, and pattern data for the energy management system. The pattern data module monitors the data felt and gathered by the various smart home sensors using these five modules. This information is examined to find the best patterns in the data, which are then sent into the recommendation system.

Administration Layer

This layer executes and controls the tasks necessary to satisfy the application layer's user needs. The service layer ensures communication between the presentation and administration layers using the REST API, Recommendation system, and service selector. User management, Home and Device Management, Optimized Pattern Finder System, and Dashboard are the four categories of tasks done by the administration layer. 4.4 Service and Security Layer This layer is separated into two sub-modules i.e., Service Layer and Security Layer.

Service and Security Layer

This layer is separated into two sub-modules i.e., Service Layer and Security Layer. 4.4.1 Service Module The application and management layer are linked by this layer. Additionally, this layer includes several

REST APIs that enable users to access all HEMS features. IoT Service Selector, Recommendation System, and REST APIs are the primary components of this layer

Security Module

This layer ensures data security and, as a result, the security and privacy of the gathered data from the device layer. This layer covers two security components: authorization (API Key, Basic Authorization, Hash Message Auth. Code, OAuth, and so on) and authentication (API Key, Basic Authorization, HashBased Message Authorization Code, OAuth, and so on) (Pass Authentication Protocol, THAP, EAP, SFA

User Interface Layer

This layer establishes a connection among the operator and the structure over a mobile application or web application. Thus the proposed architecture has five layers which make system maintenance easier and increase scalability. The architecture aims to create an optimal pattern finder system that analyzes energy consumption patterns in the home environment. These discovered patterns are used in the service layer of recommendation systems. These recommendation systems provide customers with personalized recommendations and aid in reducing energy use.

12.3 How Does It Work

Algorithm:

Input: Energy consumption data from IoT sensors

Output: Optimized energy usage and reduced energy waste

1. Pre-process the data to remove noise and outliers and normalize the data.

2. Analyze the energy consumption data to identify patterns and trends.

3. Extract features for DNN, ML algorithms training and prediction.

4. Build a deep neural network and train it on the extracted features.

5. Use the trained DNN to predict energy consumption for different appliances in real-time.

6. Develop an energy optimization algorithm based on the predicted energy consumption

And dynamic pricing information.

7. Schedule the operation of different appliances to optimize energy usage and reduce

Energy waste.

8. Implement a real-time monitoring system to track energy consumption and optimize

Energy usage based on the energy optimization algorithm.

9. Provide feedback to the user on energy consumption and savings.

10. Develop a user interface for the system that enables the user to view energy consumption and control appliances remotely.

11. Use cloud computing to enable remote access to the system.

12. Return optimized energy usage and reduced energy waste.

13. Notification to the user about the consumption of energy on daily basis and we can analyse monthly, quarterly and yearly.

14. The user can control, monitor the appliances using the smart phones

Visualize energy

Optimize and manage energy flows

Smart energy management systems are often accompanied by user-friendly mobile apps that allow for remote monitoring and control. These apps typically feature intuitive dashboards that display energy consumption data in a clear and concise manner.

Through the app, users can gain insights into their energy use patterns, identify areas of high consumption, and monitor the effectiveness of implemented energy-saving measures. Some apps also allow users to control smart devices and appliances remotely, further optimizing energy use.

12.4 **Software's, Frame work, component's used**

- Smart Home Automation Platforms- Samsung Smart Things, Apple Home Kit, Google Nest.
  These platforms provide the foundational software framework for integrating and controlling smart devices and appliances within the home.
- Energy Management Software-These applications specifically focus on monitoring and managing energy consumption within the home. They often include features for data analytics, optimization, and user interface. Example-Efergy, Sense, grid point.
- Mobile Apps and Web Portals: Most Smart HEMS systems offer user-friendly interfaces accessible via mobile apps or web portals. These interfaces allow homeowners to monitor energy usage, control smart devices remotely, and receive notifications.
- Cloud Services and Data Analytics: Many Smart HEMS utilize cloud-based services for data storage, processing, and analytics. These services enable advanced functionalities such as predictive energy usage modeling, integration with utility programs, and remote access like AWS.
- OpenADR (Open Automated Demand Response): A standard used for communicating demand response signals to Smart HEMS systems

Machine Learning Algorithms:

- Pattern Recognition: Identifies usage patterns based on historical data and adjusts energy management strategies accordingly.
- Anomaly Detection: Detects abnormal energy consumption patterns or device malfunctions, triggering alerts for homeowners to take corrective action.
- Personalization: Learns user preferences and adjusts automation settings for devices like thermostats and lighting based on individual behavior

  Support Vector Machines
  DNN, RNN, LSTM can be used

12.5 Cost Of Building Depends on

1. **Hardware Costs**: Smart HEMS typically involve hardware components such as sensors, smart meters, controllers, and possibly smart appliances. The cost of these components can vary based on quality, brand, and the number of devices required per household.
2. **Software Development**: This includes the cost of designing and developing the software platform for the HEMS, which involves creating the user interface (UI), backend infrastructure, data analytics algorithms, and integration with smart devices and utilities. The complexity of the software and the number of features will heavily influence development costs.
3. **Integration and Compatibility**: Ensuring compatibility with existing smart home systems and devices may require additional development efforts and cost. Integration

with utility providers and energy management protocols (such as Zigbee, Z-Wave, or Wi-Fi) also adds to the complexity and cost.

4. **Data Security and Privacy**: Implementing robust security measures to protect user data and ensure privacy compliance (such as GDPR or CCPA) is crucial and may involve additional development costs.
5. **Testing and Quality Assurance**: Comprehensive testing to ensure the reliability, performance, and security of the HEMS across various scenarios and devices is essential. This includes testing for interoperability, usability, and edge cases, which can impact development costs.
6. **Deployment and Support**: Costs associated with deploying the system to users, providing technical support, and ongoing maintenance and updates should also be considered.
7. **Regulatory Compliance**: Depending on the geographic location and target market, compliance with regulatory standards and certifications (e.g., energy efficiency regulations, safety standards) may be necessary, adding to development costs.

Due to the variability and complexity involved, it's challenging to provide a specific cost estimate without detailed project requirements. However, developing a robust Smart HEMS can be a significant investment, typically ranging from tens of thousands to hundreds of thousands of dollars or more, depending on the scope and scale of the project. It's advisable to work closely with experienced developers and consultants to accurately assess and plan for these costs based on specific project needs and goals.

13.0 **Code Implementation**

For coding I have taken the Dataset similar to the Project from Kaggle

Smart home.CSV

The problem to be addressed in this project is the inefficient use of energy in modern houses. More families are incorporating smart appliances and gadgets as advances in technology occur, yet frequently lack an organized strategy for monitoring energy use. This inefficiency results in higher energy costs, more severe environmental impact, and plausible equipment wear and tear. To solve the dilemma of optimizing consumption of energy, this project will investigate the integration of data science, machine learning, and smart home technologies.

GitHub Link : https://github.com/chandanah2812/SHEMS-Machine-Learning

14.0 Conclusion

Smart energy apps offer several practical benefits for users looking to manage their energy consumption more effectively:

1. **Real-Time Monitoring**: Users can monitor their energy usage in real-time through the app, gaining insights into which appliances or activities consume the most energy. This awareness helps in making informed decisions to reduce consumption and lower utility bills.
2. **Remote Control**: Many smart energy apps allow users to remotely control their smart devices and appliances. This feature enables them to turn off lights, adjust thermostat settings, or schedule appliance usage even when they are away from home, optimizing energy use and ensuring comfort.
3. **Energy Efficiency Tips**: Smart energy apps often provide personalized tips and recommendations based on the user's energy usage patterns. These suggestions help users identify areas where they can make adjustments to improve efficiency and save energy.
4. **Integration with Smart Devices**: They integrate seamlessly with other smart home devices and systems, creating a cohesive ecosystem that enhances overall automation and convenience.
5. **Energy Usage History and Trends**: Users can access historical data and trends regarding their energy consumption through the app. This information allows for long-term planning and adjustments to further optimize energy usage patterns.
6. **Cost Savings**: By effectively managing energy consumption and reducing waste, users can achieve significant savings on their energy bills over time.
7. **Environmental Impact**: Optimizing energy usage through smart energy apps contributes to reducing carbon footprints and promoting environmental sustainability.

In conclusion, smart energy apps are valuable tools that empower users to take control of their energy usage, save money, and contribute to environmental conservation efforts. They provide actionable insights and remote control capabilities that enhance convenience and efficiency in managing home energy consumption.