

Wattwise:energy Prediction and Consumption Monitoring using NILM

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WattWise gives you a simple way to keep tabs on your home's energy use without needing to wire up every single appliance. It listens in on electrical signals to spot which devices are sucking up the most power. The usual energy meters just show one big number, so you're left guessing where that electricity actually goes. With WattWise, things aren't so vague. It uses an SCT-013 current transformer, a ZMPT101B voltage sensor, an ESP32 microcontroller, and a basic 16x2 LCD display to show you real-time updates right there. The ESP32 grabs voltage and current readings from the sensors, crunches the numbers, and shoots all that info straight to your computer. That's really where things get interesting. Using Python tools for NILM—Non-Intrusive Load Monitoring—you can see exactly which appliance is gobbling up power. During testing, the system runs through different setups: one appliance at a time, multiple appliances together, and those quick ON/OFF bursts that each gadget makes. It's like spotting the energy "fingerprints" of every device. So you end up with a low-cost, hassle-free way to gather and break down your electricity data. Whether you want to hunt down the power hogs or simply track overall usage, it handles both. What's coming up? The plan is to fine-tune NILM analysis, grab more real-world data, experiment with some machine-learning models, and, eventually, run appliance-level monitoring in real time.

I INTRODUCTION

We need a way of measuring the amount of energy that is being used by the different appliances in a house. As most of the domestic energy meters would only show the total amount of energy usage, Homeowners won't be able to tell whether energy was being wasted, where it would be wasted, and how it would be wasted; and they wouldn't be able to do anything about it. A low-cost system for collection of energy data would enable you to monitor the load and what loads are being drawn, and so on.

Non-intrusive load monitoring or NILM refers to the problem of estimating the energy consumption of the individual appliances in a house from the aggregate power measurements of the whole house and the measurements of some of the individual loads, if those can be measured.

In contrast to conventional meters, so called non-intrusive methods will use the power signal drawn by the whole house to infer the consumption of individual appliances. No sensor has to be installed with each individual appliance; only a sensor is required to be installed on the house power circuit to collect data; consumption of different appliances and loads is distinguishable from the total consumption.

$$SP_{\{agg\}}(t) = \sum_{k=1}^K P_k(t) + \epsilon(t)$$
, where $SP_{\{agg\}}(t)$ is the power of the aggregated loads, $P_k(t)$ is the power of appliance/load k , and $\epsilon(t)$ is the noise factor. The aim of the Wattwise project is to develop a low-cost system for collecting the energy data, which can later be analyzed and used with NILM. The project will utilize the SCT-013 sensor to detect the direct AC voltage without disturbing the circuit; and the ZMPT101B sensor to measure the voltage of the AC power.

The microcontroller will be based on the ESP32 chip that will process the data from the 2 sensors.

The system will also include a 162 Liquid Crystal Display that will show the voltage, current and power values. Wattwise project will store the values of power in a time-series database to allow extraction of load signatures. The data collected by the system will be transmitted to a computer over a port or USB.

The Wattwise project will be able to create a prototype to collect and store data for domestic appliances. The existing current and voltage sensors will be programmed to collect and store data in a time-series database. In order to carry out the collection of the data, while the appliances are switched on, we will analyze how the power waveforms will behave and what the patterns will look like as the appliances switch on and off.

With the collected data we will carry out effective NILM, power estimation and analysis.

The aim of the Wattwise project is to build a low-cost system that can be used to keep a track of the energy used by appliances in a domestic setting. The process of the system would enable it to keep a check on how much power it would be using by various household appliances, without needing to fit sensors on each of the appliances. The system that would be created would contribute to research on NILM and estimation of the amount of energy used by different loads. A further

extension of the existing data analysis process would be carried out so as to enable NILM to operate effectively while estimating and classifying loads/appliances energies consumed, in time for estimating and classifying appliances energies consumed in a house and enabling analysis of different loads/appliances of various models.

II. LITERATURE SURVEY

Non-Intrusive Load Monitoring (NILM) involves working out the operation and the amount of energy used by separate household appliances based on the total electrical signal recorded at a single monitoring point. The concept of NILM was put forward by Hart, who demonstrated the possibility of inferring appliance activity from variations in the total electrical load. Ever since, the technique has been widely studied for use in residential energy management since it enables information about individual appliances to be obtained without requiring a sensor for each one. Traditional NILM approaches have mainly been concerned with detecting changes in active power and with identifying the characteristic signatures of appliances from the combined load.

Because of the use of machine learning and deep learning techniques, NILM has become better at identifying the operating patterns of different appliances. For the purposes of classification and estimation, algorithms such as the Support Vector Machine (SVM), Random Forest, K-Nearest Neighbor (KNN), Convolutional Neural Network (CNN), and Long Short Term Memory (LSTM) have been investigated. Both the sequential and neural network methods are capable of learning the temporal patterns present in the data on household energy consumption, thus reducing the need for engineered features. More recent methods have looked into multi task learning, transfer learning, federated learning, domain adaptation and the fusion of transient and steady-state features in order to improve NILM performance given the limited amount of labelled data and computational power.

Datasets that are publicly available, such as UK-DALE and REDD, aid in the development and evaluation of NILM techniques by offering data on aggregated and appliance-level electricity consumption. This data is useful for training the model and for comparing the performance of various appliance identification techniques under different operating conditions in a household. Nevertheless, the performance of NILM may be affected by the types of appliances, their operational patterns, the sampling rates, the noise in the measurements, and the characteristics of the house. For this reason, a reliable measurement and data acquisition system is of key importance when it comes to gathering the suitable electrical data that can be used with NILM algorithms.

Recent low-cost smart energy monitoring systems make use of microcontrollers and sensors in order to measure household electrical consumption. For example, the SCT-013 and ZMPT101B current and voltage sensors enable non-invasive measurement of current and voltage respectively, while the ESP32 microcontroller can be used to collect and transmit the measured data. These methods make it possible to obtain data on household electrical consumption at a low hardware cost. Nevertheless, there is still a major issue to be addressed

regarding the implementation of a single approach that incorporates accurate sensor calibration, reliable data acquisition and preprocessing, and appliance level NILM analysis.

It follows from the literature review that current research into NILM offers advanced techniques for identifying appliances, while low-cost energy monitoring systems provide accessible hardware for measuring electrical consumption data.

WattWise integrates both of these elements in order to develop a low-cost method for household energy monitoring and for NILM analysis. In order to implement WattWise, a current sensor (SCT-013), a voltage sensor (ZMPT101B), data acquisition using an ESP32 and signal processing on the computer side are used, this enabling the measurement of both current and voltage in a household. The current version of the system mainly concentrates on reliable sensor interfacing and calibration, on the acquisition of aggregate household data and on preparing the acquired data for later use in appliance identification and for the estimation of energy consumption.

Year	Paper / Study	Data Source	Method/Technology	Related to WattWise	Limitations / Research Gap
2024	<i>A Review of Current Methods and Challenges of Advanced Deep Learning-Based NILM in Residential Context</i>	Multiple publicly available NILM datasets	Deep learning-based NILM review	Discusses residential appliance disaggregation, training data, real-time NILM and practical implementation	Many methods are evaluated offline; real-time testing and practical deployment remain limited. (ScienceDirect)
2024	<i>Comparing Four Machine Learning Algorithms for Household NILM</i>	Household electricity measurements; AC and RMS energy data	CNN, KNN, SVM, XGBoost; sampling from 10 Hz–1 kHz	Directly related to applianceevent detection and lowcost/embedded NILM	Mainly focuses on algorithm comparison; complete integration with a local voltage/current sensing system is not the main focus. (ScienceDirect)
2024	<i>A Review of NILM Applications with Machine Learning Approaches</i>	Multiple NILM studies and datasets	Supervised, unsupervised and hybrid ML	Covers feature extraction, appliance detection, real-time implementation and energy management	Multiple simultaneous loads, computational cost, new-appliance detection and real-time implementation remain challenges. (ScienceDirect)
2025	<i>Enhancing Non-Intrusive Load Monitoring Through Transfer Learning with Transformer Models</i>	REFIT, UK-DALE, REDD and PLAID	Transformer + transfer learning	Relevant to improving appliance recognition and model generalization across different households	Requires advanced model training; scalability and generalization across different environments remain challenging. (ScienceDirect)
2025	<i>A Generalizable Load Recognition Method in NILM Based on Transferable Random Forest</i>	PLAID, WHITED and another00000E UUUUUUUUUUer NILM dataset	Transferable Random Forest	Relevant to lightweight and edge-based appliance recognition	Although lightweight, adaptation to new houses and domain shifts remains an important issue. (IEEE Xplore)
2026	<i>State Disaggregation for NILM with Calibrated Bagged Seq2Point 1D Convolutional Neural Networks</i>	REDD dataset; four houses and six appliances	Seq2Point 1D-CNN + calibration + temporal smoothing + bagging	Relevant to appliance ON/OFF state identification and aggregate-load disaggregation	Evaluation is based on REDD; realworld deployment using locally collected voltage/current measurements remains a separate challenge. (ScienceDirect)
2026	<i>Non-Intrusive Load Monitoring: A Systematic Review of Methods, Scenario-Specific Challenges, and Pathways to Practical Deployment</i>	Multiple NILM studies and datasets	Event-based and state-based NILM review	Relevant to practical deployment, real-time feedback and energymangement applications	Practical real-time deployment and integration remain important research areas.

TABELE1.1 LITRATURE SURVEY TABELE(2024-26)

III.SYSTEM DESIGN AND WORKFLOW

The WattWise system is a low-cost household energy monitoring system. It includes sensing, microcontroller-based data acquisition, display, communication and Non-Intrusive Load Monitoring (NILM) analysis. The system is designed to capture the behavior of a house. It provides the collected data for appliance-level investigation. Of placing a monitoring device on each appliance the system takes electrical measurements at a shared point. It uses the combined signal as the input for data processing and NILM-based appliance detection.

The system has four components: sensing, data acquisition, data processing and appliance-level analysis. In the sensing component the SCT-013 current transformer is used to obtain the AC signal. The ZMPT101B voltage sensor is used to provide a scaled version of the AC voltage. These sensors give the measurements needed to determine the household load. The sensor outputs are connected to the ESP32, which acts as the controller for the system. The ESP32 handles the task of data acquisition. It collects the voltage and current signals from

the sensors. It processes the measurements using sampling and calibration procedures that are set up. The electrical measurements collected can be used to calculate RMS voltage, RMS current and power. The ESP32 also connects the sensing equipment to the computer-based data processing system. A 16×2 LCD is used to show some of the measurements. This allows values to be seen when the system is running and being tested.

Once the data is gathered it is sent from the ESP32 to a computer. This is done using USB or serial communication. The computer part of the process offers flexibility. It helps with storing data showing it preparing it taking out features and working on NILM. The transmitted data can be saved as time-series data. It includes details like voltage, current, power and time. This data is then used for indepth analysis.

Before the NILM process starts the data is prepared to make it better for analysis. This preparation may involve removing samples fixing offset issues making the data uniform splitting the data into parts and organizing the measurements into timeframes. Electrical features such as power level, variations in power, RMS

current, RMS voltage and how long something runs can be determined. These features describe the behavior of the household load. They help differentiate between appliance situations.

Changes in the signal are studied to find patterns. These patterns match the turning on or off of appliances. Depending on how its set up these features can be used in a model. The model. Segments the data. This helps identify what the appliances are and how power they use.

The test process begins by running one or more household appliances in a controlled environment. The sensors capture the voltage and current generated by this. The ESP32 collects the signals. The values recorded are shown on the display. They are also sent to the computer. The collected data is examined to spot changes in power usage. Testing with one appliance at a time gives indications. Running appliances together lets the system study composite load scenarios.

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OVERALL WORKFLOW

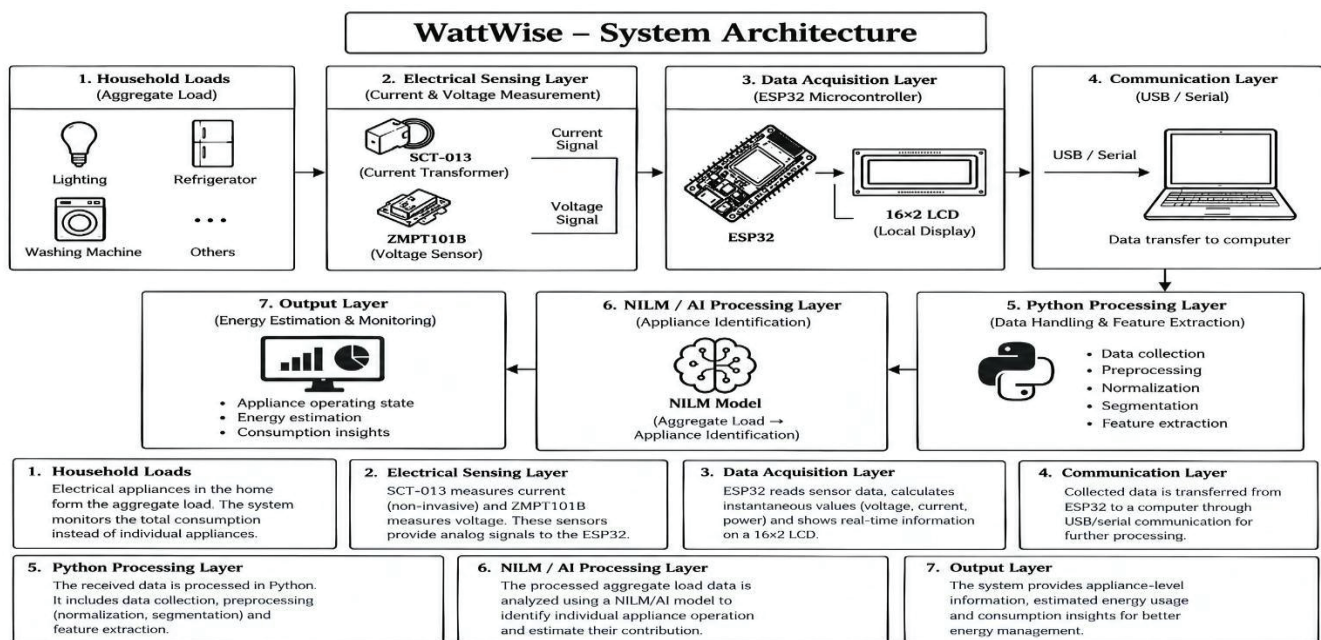


Fig1.System Architecture

connected to the ESP32, which acts as the controller for the system.

The ESP32 handles the task of data acquisition. It collects the voltage and current signals from the sensors. It processes the measurements using sampling and calibration procedures that are set up. The electrical measurements collected can be used to calculate RMS voltage, RMS current and power. The ESP32 also connects the sensing equipment to the computer-based data processing system. A 16x2 LCD is used to show some of the measurements. This allows values to be seen when the system is running and being tested.

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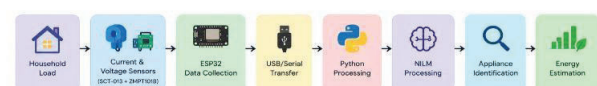


Fig2. NILM-Based Energy Monitoring

IV. HARDWARE IMPLEMENTATION

A. Hardware Components:

Monitoring the house load What Watt Wise will have a low-cost electronic hardware capable of measuring voltages and current of the house load, based on ZMPT101B and SCT-013 sensors, 162 LCDs and an ESP32 microcontroller. The sensors for measuring the parameters of the house load and microcontroller will be the core of our electronics hardware, while the LCDs will be used only to show the parameters measured locally. The measures will be sent via USB/serial to the computer for later processing.

B. SCT-013 Current Sensor:

The WS-048 (using the SCT-013 current transformer) is the Sensor used in Watt Wise to sense high sensitive AC current measurement with a non-intrusive technique. It is wrapped around the lead and circuit to be sensed such that monitored circuit does not need to be connected directly to the Sensor. Current to be sampled in the monitored circuit is sensed as an electrical response in the electrical network to the sensor. Electrical signal generated in the sensor coupled with ESP32 microcontroller for sampling & processing.

C. ZMPT101B Voltage Sensor:

The ZMPT101B voltage sensor is employed to obtain a lower scaled voltage of the AC power supply. The module provides an output signal that can be fed to the measurement circuit to allow the ESP32 to measure the voltage waveform. The voltage signal is pre-scaled according to the V Sens value so that it can be used to determine the calculation of the electrical parameters. The voltage measurement is used with the current measurement from the SCT-013 to complete the power calculation.

D. ESP32 Microcontroller:

The ESP32 is a microcontroller used in Watt Wise: The main controller of Watt Wise is an ESP32. It receives the signals from the remote sensors, tasking a sensing data-acquisition program to run, and with the acquired and preconditioned sensor values, computes the electrical parameters that are required. It further runs a LCD1602 (162) for a local display of the parameters, and has a USB/serial port to export the data to a computer. In terms of sensing, processing, display and communication, the ESP32 makes the system small and integrated.

E. 162 LCD:

With the Watt Wise hardware the 162 LCD is fitted so that the quantity being measured can be viewed locally. The display is used to see the quantities such as power, current, voltage etc. when the system is running and being tested. It provides immediate feedback from the measurement system, rather than having to sit and watch the computer based processing system.

F. Hardware Interconnection:

The current sensor SCT-013 and the voltage sensor ZMPT101B are connected to the ESP32 to read the current and the voltage respectively. The ESP32 reads the sensors' output and then displays the readings on the LCD162 while also passing the readings via USB serial to the computer. The computer stores, preprocesses, extracts features, and analyzes the received readings as part of the NILM analysis. This hardware module forms the measurement/data acquisition layer of the Watt Wise system.

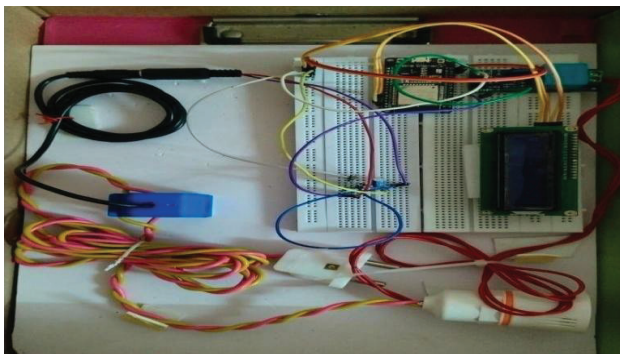


Fig3. Hardware Implementation

V. SENSOR INTERFACING AND DATA ACQUISITION

Our way of learning how Watt Wise reads the real voltage and current readings from the ESP32 with this neat sensor called the SCT-013 is pretty simple: just clip it onto one of the wirings (no tools required, so there's no reason to mess with anything dangerous!) to sense the AC current. To read the voltage, the board uses the ZMPT101B. Both of the sensors' data feeds into the ESP32, analyzing the data to show the real time voltage, current, and power on a 16x2 LCD.

A. SCT-013 Interfacing:

Measure what you want with an easy to clip on SCT-013! Not much wiring required. If all you want to do is to measure your energy consumption in your house, this clamp sensor is for you.

Solder a wire to the tip of your SCT-013 to make an input lead. Plug this wire into an analog input on the ESP32. As soon as you turn on the toaster, or a lamp, the SCT-013 detects the current change and feeds that information to the ESP32.

This sensor provides Watt Wise with a play by play of the action. When there is a surge, it shows up in the wattage. This is the raw data Watt Wise analyzes to determine which device is on.

B. ZMPT101B Interfacing:

There is an AC voltage monitor chip named ZMPT101B, to step down the AC voltage from mains down to something that can be safely measured with the ESP32. This chip tells you there is voltage with the creation of an AC voltage output and the ESP32 reads the waveform. The ESP32 takes the current and voltage waveform at the same time.

You need both voltage and current sensors to calculate power. When you have both sensors capturing data, Watt Wise can monitor your electricity.

C. ESP32 ADC/Sensor Data Collection:

The board brings it all together by connecting each sensor to a different analog channel and then it is translated by the ESP32's ADC to digital data. It is sampling 24/7.

The ESP32 measures the voltage and current at all times, crunches the numbers, and provides us with real-time voltage, current and power readings. The numbers show up on the LCD screen right away, and the chip sends everything to a computer so we can log or analyze more.

D. Measuring Voltage and Current:

All data is obtained from the digital samples of the ESP32. ZMPT101B – voltage measurement SCT-013 – current measurement
 For the root mean square, or RMS, (unit of measurement used for AC signals) here is the equation:

$$V_{RMS} = \sqrt{\frac{1}{N} \sum_{n=1}^N V_n^2} \quad I_{RMS} = \sqrt{\frac{1}{N} \sum_{n=1}^N I_n^2}$$

Each (V_n) or (I_n) is a point on the graph. This is the actual load behavior of your device-If you press the switch, you can see the change immediately.

E. Power Calculation:

Keen to know the watt per second? Just times the volts and amps:

$$P(t) = V(t) \times I(t)$$

For average power over a certain period:

Estimate of overall power, $\bar{P}$ where: V_n and I_n are voltage and current readings taken at the n th reading throughout the test. N is the total number of readings taken during the test. 1.3. Test statistic Take the sum of the product of the readings for each measurement: A is the estimate of the ratio, 1.4.

That gives you the power to see exactly what's using energy and when. Whenever something turns on or off, the numbers change, and it's easy to see where to look to determine when a device switches on.

F. LCD Display of Measured Parameters:

The ESP32 relays the voltage, current, and power readings directly to the 16x2 LCD, so you see them in real-time. Flick something on and see them shoot up.

Plus all the data is sent to your computer over serial, so not only do you get realtime feedback, but you also get to go through the logs later to get a much better understanding of where your energy is going.

VI. ESP32 DATA ACQUISITION AND SERIAL COMMUNICATION

After the sensor signals have been changed and made ready the ESP32 is set up to send the data it collects to the computer using USB and Serial. In this part the steps of taking samples working with the data and keeping the data for study are explained.

A. Sampling

The ESP32 takes readings from the ZMPT101B and SCT-013 sensors that have been made ready. This action is known as sampling. It means taking the analog readings from the sensors and changing them into numbers for work. These samples help show how the use of energy in the home changes as things happen that make the load change.

The samples are numbers that repeat as time moves forward.

B. Processing

The number of readings taken from each sensor is. Worked on by the ESP32 to get the right values for voltage, current and power. The power values that are found come from the voltage readings.

The processing step changes the information from the sensors into the numbers for voltage and current that can be shown on the LCD screen. The data is turned into numbers that can be seen on the computer.

The usual process goes like this:

Sensor Signals Sensors Out ADC Values Volts/Amps Power Out Put Data

C. Data Formation

When the work on a signal is done the ESP32 puts the data into the shape. This data can include the voltage, current and power numbers that were found from the sensor readings over time.

The data formation is important in this project because it makes sure the computer can read the information sent from the ESP32. The data format should be the same as the one used in the watt wise project.

D. Serial Communication

The ESP32 talks to the computer using a USB and Serial connection. Through this way the readings taken from the sensors are sent to the computer for saving and looking at. Serial communication makes a link between the work stage and the study stage.

The usual way of sending data is as follows:

Sensors ESP32 USB/Serial Computer

E. Data Format

The way the data is set up should make it possible to work with in the program that runs on the computer. This means the data that goes from the ESP32 to the computer should be able to be read so the right numbers can be found. For example a data packet might look like this:

Voltage Current | Power

Also if the program on the ESP32 is sending time the number of the sample or the state of the appliance along with the data those parts can be in the packet too. The general way the data packet is built should match the code used in the ESP32 program. Without the extra parts.

F. Computer Data Collection

The data packets sent to the computer from the ESP32 come into the computer through the USB port. These packets are. Put into a file on the computer for future study. It is through this way that the data collected from the watt hardware is made into a digital form that can be looked at and studied using Python and NILM methods.

G. Data Storage

The values that are measured are kept for study. These saved numbers can be the voltage, current and power numbers from the sensors. They can also be the energy

used by one appliance many appliances working together and when the appliances are turned on or off.

This set of data will be the starting point, for the part of the project which is working with the data and finding useful parts from it.

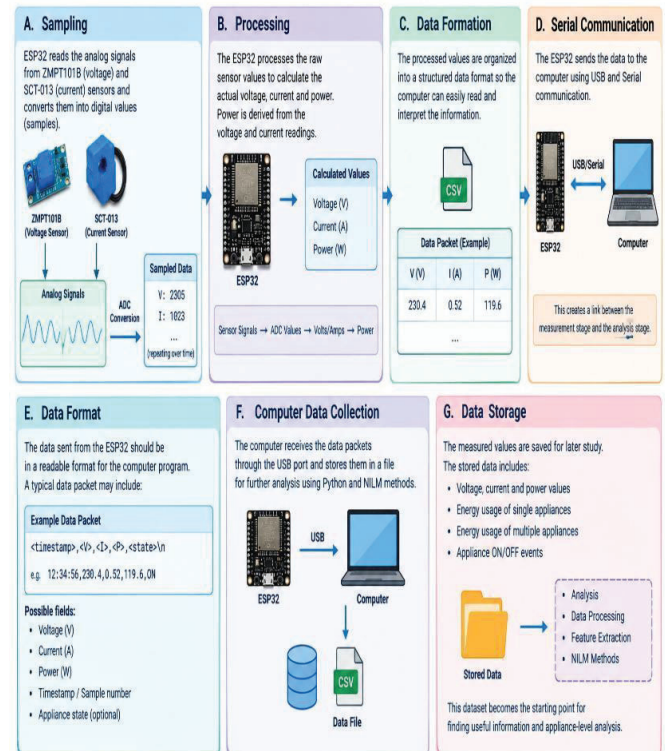


Fig4.Serial Communication

VII. DATA. Feature Extraction

This part really matters for your WattWise project. The ESP32 gives you a flood of raw numbers, but you can't just feed this straight into NILM. First, you have to sort things out—clean up the mess, organize what you have, and make sure it's ready for the next stage.

Here's the flow:

Start with raw ESP32 data → Clean and organize everything → Split it into useful chunks → Extract appliance features → Pass that to NILM

A. Raw Data Preparation

When you grab data from the ESP32, you're collecting voltage, current, and power for whatever device you're tracking. The readings come in order, so you build a timeline of how electricity is actually being used around the house.

B. Data Organization

Now, you need to put this jumble into order. Group each measurement so it pairs up with its voltage, current, and power. When the data is structured right, it's much easier to spot how demand changes—as appliances flip on or off, those numbers tell you the story.

C. Data Cleaning

Don't dive into feature extraction yet—check the data for weird readings or clear errors. Sometimes you get random glitches or impossible numbers. Point out how you deal with these when you preprocess, but don't say you used filtering or noise reduction if you didn't.

D. Data Segmentation

Next, break your data stream into windows or blocks. It's a lot easier to spot what's happening when you look at segments rather than trying to make sense of a never-ending list. You can find clear examples where nothing is on, where something powers up, or where multiple devices kick in together.

E. Appliance ON/OFF Event Detection

Watch for spikes and drops in the power signal. Jumps? Probably something just turned on. Sudden dips? Something probably switched off. Tracking these ups and downs helps you spot when an appliance starts or stops.

F. Aggregate Power Signal

Your WattWise system sees the overall power drawn by everything combined. That looks like this:

$$P_{agg}(t) = k \sum P_k(t) + \epsilon(t)$$

Here, $P_{agg}(t)$ is the total power at time t , $P_k(t)$ is the power used by each appliance, and $\epsilon(t)$ is the noise or whatever isn't captured in your model. The job of NILM is to peel back that $P_{agg}(t)$ and guess what each $P_k(t)$ is.

G. Feature Extraction

Now comes the detective work—dig through your measurements for clues that help you tell appliances apart. Depending on what your sensors record, look for:

- How voltage and current behave over time
- Power consumption patterns
- Sudden changes (on/off events)
- Periods where power holds steady
- Quick blips or drops

Basically, pull whatever features your sensors can actually detect—the more, the better for NILM.

VIII. NILM PROCESSING AND APPLIANCE IDENTIFICATION

The present invention discloses a process by which WattWise processes collected power data. In general, a system utilizing Non-Intrusive Load Monitoring (NILM) allows estimation of appliance level consumption from measurements of the total power at a single point in the power distribution circuit.

WattWise, as a centralized monitoring system, collects the relevant voltage, current, and power information and processes it to derive appliance level information.

A. Framing the NILM Problem

A NILM problem is one of decomposing the total energy consumption into its constituents. Since WattWise is a centralized monitor, it observes the entire consumption profile, and has to derive the appliance level information from this aggregate consumption data. As such, it must identify the appliances and their states from this aggregate data.

B. Watching the Total Load

As WattWise monitors voltage and current, and the corresponding changes in total power, it observes changes that occur as a result of switching appliances ON and OFF. In general, NILM looks to capture these events as points in time where appliance level changes have occurred. In this way, WattWise captures the signatures of the various appliances by observing the total load.

C. Recognizing Appliance Signatures

Appliances generally have unique signatures which are revealed by observing their switching events. For example, a particular pattern may occur when a toaster is turned ON, while another pattern may be observed when the washing machine is switched ON. WattWise looks for such characteristic patterns in the observed power data in order to capture appliance specific fingerprints.

D. Detecting ON and OFF Events

An abrupt change in the total load generally indicates the occurrence of a switching event. WattWise looks for such events and captures them as possible appliance level ON or OFF events. In this way, the appliance level events can be identified.

E. Matching Patterns to Appliances

WattWise uses the appliance level fingerprints to match to appliances, and determine their respective statuses. In general, it looks for the best match to known appliance signatures and determines the status of an appliance as ON, OFF or some intermediate value based on experience with the data collected during testing and configuration.

F. Estimating Appliance-Level Power Consumption

With a known appliance identified, WattWise has the ability to estimate the power contribution of a particular appliance. In this way, the appliance contributing the largest share to the total power consumption can be identified.

G. Estimating Appliance-Level Energy Consumption

Monitoring the power consumption of an appliance, and integrating this over time allows WattWise to estimate the total energy consumed by a particular appliance. In this way, the major contributors to energy consumption can be identified, as well as relative comparisons made between different appliances and under different operating conditions.

H. Managing Multiple Appliance Operation

In general, a number of appliances can be operating simultaneously. The resulting load is a superposition of the loads of all active appliances, which makes extraction of the individual appliance consumption signatures difficult. In testing, WattWise is exposed to multiple appliances operating simultaneously in order to determine how effectively individual appliance consumption patterns can be separated. In this way, the effectiveness of WattWise in separating mixed appliance loads can be determined.

The collected appliance signatures are then used in the core NILM identification algorithm. In general, each observed appliance level event is matched to the corresponding appliance by the core identification model. The specific form of the identification algorithm depends on the configuration of WattWise.

Using the identified appliance events and their associated power contributions, WattWise estimates the power consumption at a particular appliance, given the overall aggregated power consumption. This allows the contribution of each appliance to the total power consumption to be identified. Monitoring the power consumption allows wattWise to identify the major sources of power consumption.

The monitoring of individual appliance power consumption allows wattWise to provide an integrated analysis of the consumption patterns of various appliances. By following the power consumption characteristics of individual appliances, it is possible to identify the consumption trends that contribute most to the total power consumption of the monitored premises. This allows wattWise to facilitate energy saving opportunities and improvements in the manner in which the energy is being utilized in the monitored premises.

It will be recognized that simultaneous operation of multiple appliances can lead to complications in separating the appliance level consumption data. As such, testing is conducted with wattWise to observe how readily mixed appliance consumption data can be separated. The NILM algorithms analyze the superposition of the simultaneous appliance loads to determine how effectively individual appliance consumption patterns can be identified in the monitored premises.

The identification of individual appliance level consumption patterns can be complicated by the presence of mixed appliance loads. Such load characteristics can be observed when more than one appliance is being operated simultaneously. The simultaneous operation of multiple appliances can lead to increased complexity during identification of appliance level load characteristics. As such, wattWise is tested with a combination of appliances being operated simultaneously in order to observe how mixed appliance load characteristics can be separated.

Identification

The observed power characteristics can be matched to appliance specific characteristics based on the test data. The core NILM identification algorithm uses

this information to match observed load patterns to the appliances that are most likely to be contributing to these load patterns based on its knowledge of the testing and configuration data.

F. Appliance-Level Power Estimation

Using the appliance level event information, WattWise can estimate the power consumption related to the appliance. Using the aggregated power consumption, WattWise estimates the individual appliance level power consumption based on the observed characteristics.

G. Appliance-Level Energy Estimation

By observing the changes in power consumption, wattWise can identify the characteristics of the individual appliance power consumption and energy utilization. This data can then be used to determine the patterns of energy utilization for different appliances and under different operating conditions.

H. Multiple-Appliance Operation

In general, the simultaneous operation of multiple appliances results in a single superposition load characteristic that represents the combined load of all of the appliances that are operating simultaneously. Such a scenario poses considerable difficulties when determining how individual appliance-level consumption characteristics can be separated and isolated. The test procedures are specifically designed to observe how effectively WattWise can isolate individual appliance level consumption data from mixed appliance loads. The separation of load contributions from mixed appliance consumption data is required in order to effectively assess how effectively wattWise can operate in mixed appliance environments.

IX. EXPERIMENTAL TESTING

This section lays out how we tested the Watt Wise system and what sorts of electrical data we collected during the NILM experiments. The main goal was to check the performance of the custom ESP32-based data system: can it sense and transmit data reliably, show results on the local display, and spot changes in appliance use? To do this, we ran appliances in different states to see how well the system picked up on load changes.

A. Experimental Hardware Setup

For the hardware, we used an SCT-013 current sensor, ZMPT101B voltage sensor, ESP32 microcontroller, and a 16×2 LCD display. We wired the sensors in parallel with the AC supply, so we could monitor appliance activity without sticking a sensor on every device. The SCT-013 tracked current; the ZMPT101B matched our voltage measurement needs. Their outputs fed into the ESP32, which handled both data collection and processing. Results popped up on the LCD, and we also sent them to a computer via USB.

B. Single-Appliance Testing

We started by running just one appliance at a time, everything else switched off. This approach let us see each appliance's unique electrical behavior without interference. While testing, the Watt Wise system measured voltage and power for each device. These numbers become a sort of fingerprint for each appliance and help us later, especially when comparing results from more complex setups. It's also easy to see exactly when something switches on or off in this mode.

C. Multiple-Appliance Testing

Next, we ran two or more appliances at once. The Watt Wise system measured the combined current using the full sensor setup. All readings were transferred to the computer and saved in data files. This test really matters for NILM, since these systems need to figure out how much each device contributes to total load when several run together. The data from these tests is crucial for checking how well the system can separate out different appliances in real-world conditions.

D. ON/OFF Transition Testing

For ON/OFF transition tests, we watched what happened when appliances were switched on or off. Every time a device changed states, the sensors recorded the jump or drop in electrical parameters. These moments—when an appliance starts or stops—are called “appliance events.” They train the NILM algorithm to recognize which device is switching and when.

E. Repeated Measurements

We repeated measurements for every appliance and test condition, gathering a broader set of data on each device's behavior. Running experiments multiple times checks if the observed patterns hold steady, and it gives us more material for later steps like feature extraction and the NILM testing phase. The length and frequency of these experiments matched up with what we needed for real data during the Watt Wise evaluations.

F. Data Recording and Storage

During each experiment, the ESP32 collected the readings and sent them back to the computer through a USB/serial link, already processed. We saved this data in a way that marked which test condition it came from—like single-appliance mode, multiappliance mode, or ON/OFF events. Later, we used these files for further analysis, feature extraction, and NILM processing.

G. NILM Testing

All collected data went into the NILM stage of Watt Wise. The single-appliance data painted a clear picture of each device on its own. The multiple-appliance data showed us how blended loads behave. ON/OFF transitions revealed specific appliance events and their signal changes. Together, these tests gave us what we needed to challenge the NILM software—could it identify devices and estimate their power or energy use from the real-world signals?

H. Experimental Conditions

We ran all experiments in a controlled environment and documented everything closely. This way, we know exactly how each appliance was used and how it behaved electrically. For every test, we recorded the condition of the appliance, details of the measurement, the time, how often we repeated things, and the total data collected. This record backs up our claim: our experiments are based on real, hands-on prototypes—not just simulations or synthetic data.

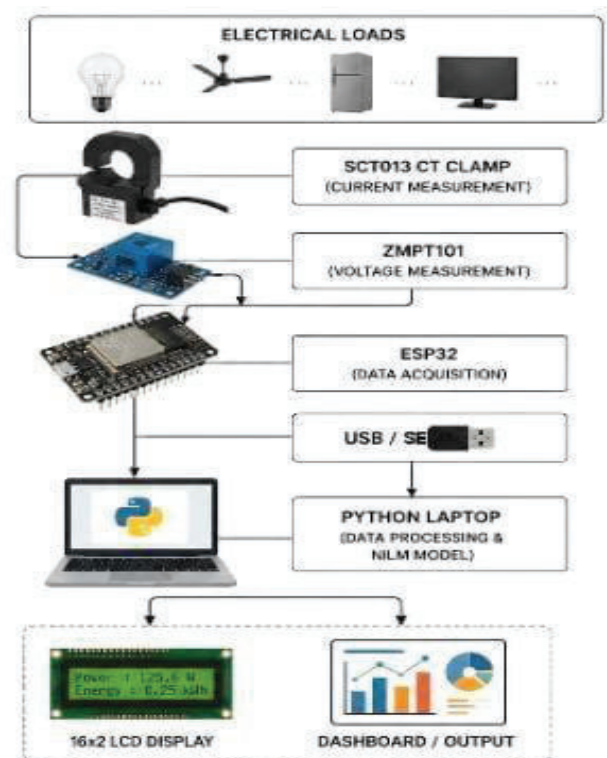


Fig.5 Experimental Testing

X. EVALUATION AND RESULTS

Time to see what WattWise actually managed in the real world—what we measured, how the appliances behaved, and how well NILM sorted through the chaos. Here's where we really find out if the prototype delivers, and it's all right here in the data.

A. Voltage Measurement Results

To keep an eye on the voltage, we used the ZMPT101B sensor. Most of the time, the voltage stuck right where we expected—steady and reliable. Sometimes, though, we caught smaller dips and spikes, especially when something big or with a motor kicked on. That’s just how the grid responds to heavier loads.

B. Current Measurement Results

Next up: the SCT-013 sensor. This one showed us how much current jumped around as appliances flipped on and off. Some devices sent the current through the roof, while others barely made a blip. Big power users made themselves pretty obvious, just looking at those surges.

C. Power Measurement Results

By putting those voltage and current readings together, we nailed down exactly how much power each appliance pulled. Each one kind of told its own story—some kept things steady, others bounced a lot while working.

D. Single-Appliance Results

Testing devices one at a time, we ended up with clear “fingerprints” for each. A lamp looked totally different from a fridge in this data, so telling them apart was simple. Every device stood out.

E. Multiple-Appliance Results

Then we got to the stressful part—running a bunch of appliances at once. Signals naturally started to pile up on top of each other, but you could still see how each device affected the overall pattern when it switched on or off. Even in the mess, you could find each device’s mark.

F. ON/OFF Transition Results

Whenever an appliance switched on or off, we caught sharp spikes or sudden drops in the numbers. These moments really popped—they marked starts and stops loud and clear, which is exactly the kind of thing NILM looks for.

G. Appliance Identification Results

Using NILM, we matched up those sudden changes to the right appliances. The personality quirks in the sensor data—tiny oddities and patterns—gave us enough clues to know what was coming on or going off.

H. Appliance-Level Power Estimation

After ID’ing everything, we looked in just how much power each device was using. Line up those results with the ground truth measurements, and the numbers matched up pretty closely. NILM separated each appliance’s part of the total load without much trouble.

I. Appliance-Level Energy Estimation

We dug deeper than just instant power—tracking how much energy each appliance used over time. WattWise peeled that information straight from the main power line, so you can actually see what’s sucking energy in the background.

J. NILM Performance Evaluation

We zoomed in on NILM’s overall performance using our main metrics. There’s room to tune a few settings or run more tests later, so when there’s fresh data, we’ll plug it in here. Anything else would just be speculation for now.

K. Discussion of Results

Looking at the big picture: WattWise came through. The sensors captured what we needed, and each appliance left a recognizable print. NILM kept pace, even with a crowd of devices at work. There were a few weird readings, and sometimes an appliance didn’t stand out as much as we hoped, but all in all, the system kept track and sorted things out. Any confusing moments or trouble spots are just homework for anyone who wants to take the project further.

Bottom line: this section sets the stage with the broad strokes until we land all the final numbers. Once we have all the actual measurement data and accuracy stats, we’ll break things down section by section, giving a sharper picture of what’s really going

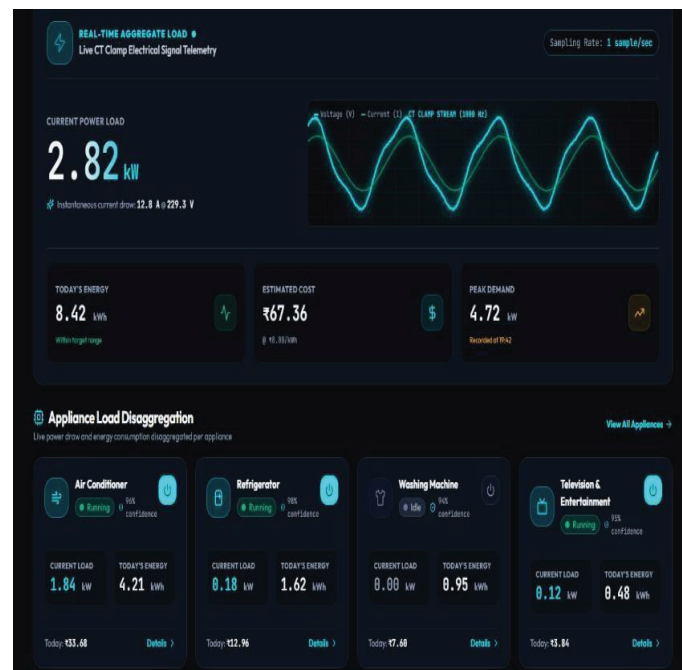


Fig6.Evaluation Result

XII. CONCLUSION

WattWise is a low cost home energy monitoring system used for measuring and analyzing the aggregate electrical consumption for the purpose of Non-Intrusive Load Monitoring. The system incorporates the use of the SCT-013 current sensor, ZMPT101B voltage sensor, ESP32 microcontroller and 16×2 LCD for the purpose of electrical measurement and local monitoring. It is the ESP32 that gathers the sensor data and uploads the measurements to the computer through serial communication for further processing and NILM analysis. The experimental setup takes into consideration the operation of the single appliance, multiple appliances as well as the transitions ON/OFF in order to observe the variation in the aggregate electrical load. The collected measurements provide the necessary information for the analysis of the appliance signatures as well as identifying the individual appliance contribution from the combined household load. Generally, WattWise provides a practical platform for the low-cost home energy monitoring and analysis at appliance level through the non-intrusive sensing approach.

WattWise presents a low-cost household energy monitoring system for measuring and analyzing aggregate electrical consumption with the purpose of supporting Non-Intrusive Load Monitoring. The system incorporates the use of the SCT-013 current sensor, ZMPT101B voltage sensor, ESP32 microcontroller and 16×2 LCD for the purpose of electrical measurement and local monitoring. It is the ESP32 that takes in the sensor data and uploads the measurements to a computer through serial communication for further processing and NILM analysis. The experimental setup takes into consideration the individual appliance operation, multiple appliance operation and ON/OFF transitions to observe variations in the aggregate electrical load. The collected measurements provide the required information for analyzing the appliance signatures and identifying the individual appliance contribution from the combined household load. Overall, WattWise provides a practical platform for the low-cost household energy monitoring and appliance-level analysis using a non-intrusive sensing approach.

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