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THE THINKING HOME

DESIGNED TO SENSE, LEARN, AND ADAPT AROUND YOU

NANOPOWER IN SMART HOME APPLICATIONS

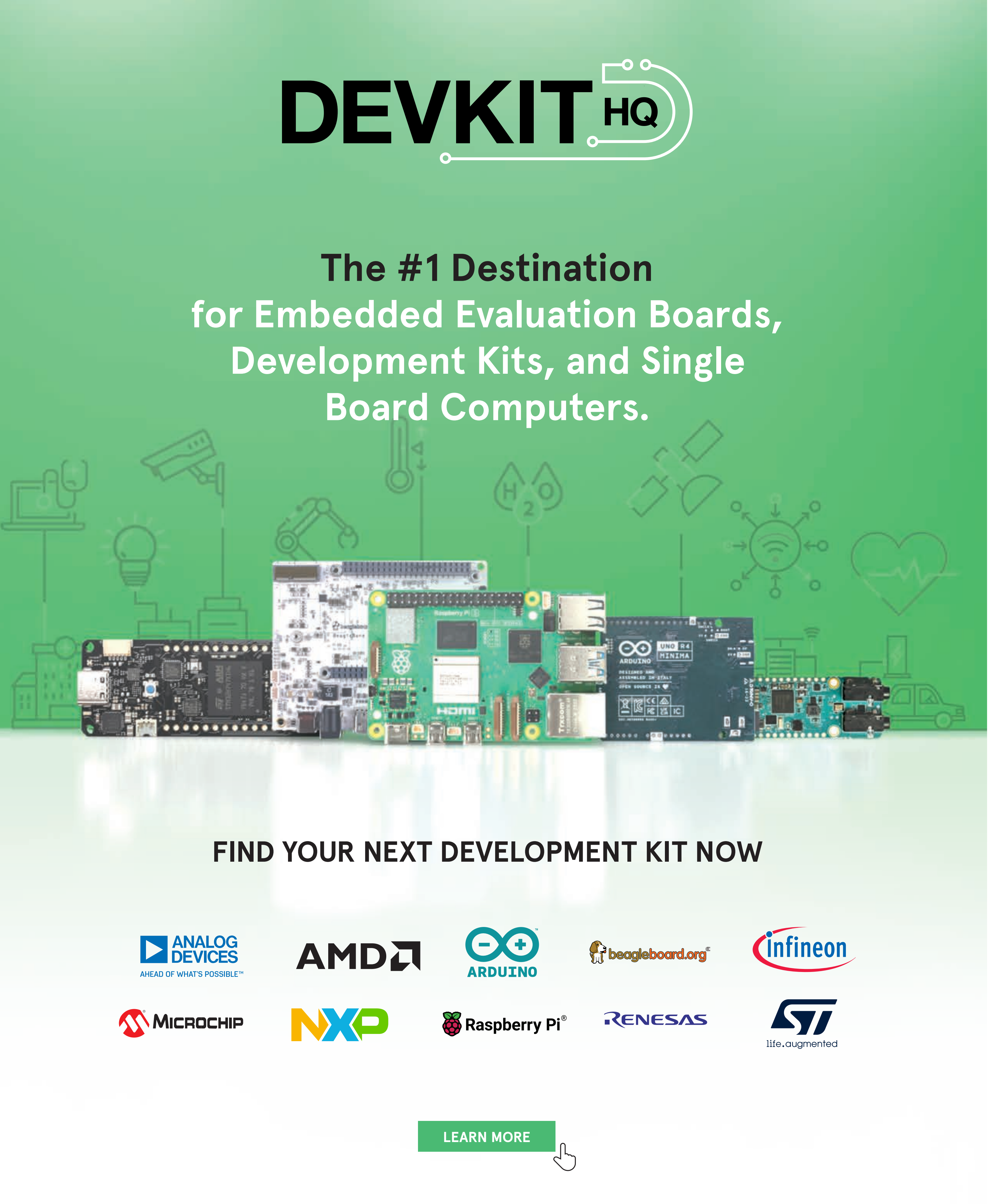
+

MACHINE LEARNING-POWERED SMART THERMOSTAT

REDEFINING SMART HOME HUB DESIGN

REAL-TIME ENERGY MONITORING

VOICE-ACTIVATED AI HOME AUTOMATION ASSISTANT



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WELCOME

Connected homes are rapidly evolving from simple automation systems into intelligent environments that actively sense, learn, and adapt to human presence and behaviour. What once relied on timers, isolated devices, and manual control is now transforming into a dynamic ecosystem of interconnected systems, where sensors, edge intelligence, and cloud connectivity work together to deliver seamless, context-aware experiences across every part of the home.

This transformation is driven by the convergence of embedded computing, wireless communication, advanced sensing, and machine learning. From energy management and real-time monitoring to voice interaction and adaptive climate control, modern smart home systems are no longer reactive, they are predictive, responsive, and increasingly autonomous. Engineers are redefining system design by integrating multi-protocol connectivity, low-power architectures, and intelligent control at both the edge and the cloud, enabling devices that can continuously optimise performance, efficiency, and user comfort.

In this edition of eTechJournal, "**THE THINKING HOME**," we explore the technologies shaping this next phase of smart living, from intelligent hubs and machine learning-powered control to energy-efficient sensor systems and real-time monitoring solutions. As homes become more aware, adaptive, and connected, the focus shifts from controlling devices to enabling environments that think, respond, and evolve around us.

The future of smart homes is not just connected, it is intelligent, adaptive, and designed around people. Let's build the next generation of living environments that truly understand how we live.

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USING NANOPOWER IN SMART HOME APPLICATIONS

FREDERIK DOSTAL,
POWER MANAGEMENT EXPERT

Smart home applications involve many technical building blocks. Some of these need to be battery-powered because they are deployed in remote locations, without any cable connections. These include sensors, switches, meters, and portable remote controls. Such devices are usually battery-powered. In order to build convenient, small form factor, reliable, and low cost systems, power management is key.

INTRODUCTION

New innovation in the nanopower space allows for single or multiple alkaline battery cells or lithium ion (Li-Ion) batteries to power such devices.

This article introduces use cases and shows two circuit examples utilizing Analog Devices' new MAX77837 and MAX18000 nanopower switching converters.

LIVING THE DREAM

Convenience is a deep-rooted desire in human nature. Despite our hard work, we strive to spend our money to make life easier. One area making significant strides is home automation with smart home technology. We want our homes to serve us better, offering more relaxation, comfort, safety, and environmental benefits.

Traditional home systems like HVAC, security alarms, yard sprinklers, and home entertainment have been around for a while. However, it took interconnected and web-based control to truly enhance convenience. In the past, resetting a sprinkler system for daylight savings might have meant digging out the instruction manual. Now, a single app on our phone can manage everything, often making basic decisions automatically.

BUILDING A SMART HOME APPLICATION

Typically, sensors need to be distributed around the house, so that the smart home can see, hear, and feel things. Classic sensors are sensing light, temperature, and movement, while more modern sensors include image recognition and other high intelligent recognition. Such sensors can detect how many people are in a certain room and they could detect if a friendly cat decided to walk up to the front door or if a burglar is checking to see through a window if any valuables are available to be stolen.

To save cost and to provide flexibility, such sensors should run without wires attached to them. This way sensors may be deployed easily in existing homes and the perfect location can be utilized. With wireless communications, such as Wi-Fi or Bluetooth®, data communication is not a difficult problem to solve nowadays. However, every sensor needs power. Supplying this remains to be a challenge for most applications.

Energy harvesting with common photovoltaic cells are used, but batteries are very often still the preferred choice. The biggest problem with smart home systems is battery run time. To make simple batteries practical and photovoltaic cells cost-effective, sensors need highly efficient power supplies. Both the standby current and the efficiency during full load operation are crucial to the design of any smart home system.

VERY EFFICIENT POWER SUPPLY USING A SINGLE BATTERY CELL BOOST CONVERTER

A simple way of powering a distributed sensor is using a primary cell, which is a disposable, nonrechargeable battery. Such batteries offer a good compromise between circuit cost, hardware components, and cost of ownership (such as cost and effort of replacing or recharging batteries). Typically, such primary cell batteries provide a voltage of 1.5 V. This is when the batteries are still fresh. Upon discharge, the battery voltage reduces to values below 0.8 V. Different battery chemistries show different voltage curves during their discharge cycle. But generally, batteries have hardly any usable energy left, as the voltages drop below 0.8 V.

Many electronic circuits need a higher operating voltage than 0.8 V. To better match the supply voltage with the operating voltage, multiple battery cells may be used in series. However, multiple cells cost more money and they require more space than just one battery cell. For this reason, there are very efficient boost regulators available, which boost a typical primary battery cell voltage in the range of 0.8 V to 1.5 V to a voltage that a smart home application can actually be supplied with, such as 3.3 V or even 5 V. Figure 1 shows such a little boost converter circuit using the MAX18000.

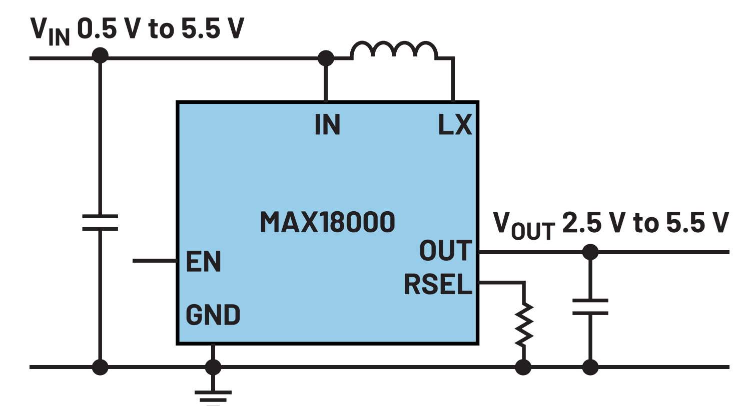

Figure 1. A simple and very efficient single-battery cell boost converter.

This circuit is compact and only requires a few external components. The DC-to-DC converter IC itself comes in a 1.07 mm × 1.57 mm package. The boost converter is equipped with two internal 3.6 A switches. The quiescent current is only 512 nA, while the output voltage is up and running. The peak efficiency is 95% and the low load efficiency, with higher than 20 µA load current, is still above 90%. The input operating voltage range is from 0.5 V to 5.5 V, making it possible to boost very low battery voltages such as 0.8 V, to useful higher system voltages.

VERY EFFICIENT POWER SUPPLY USING A BUCK-BOOST CONVERTER

Other sensor applications run with multiple battery cells or possibly a Li-Ion battery. Such voltages are a bit higher than in the example above. Typical values are around 3.7 V in the state of a fully-charged Li-Ion battery. As the cells are being discharged, a voltage of 2.8 V is about the minimum, before the energy stored in such a cell is depleted. This voltage range, from 2.8 V to 3.7 V requires a buck-boost solution to generate a nominal 3.3 V to run common circuit electronics for a typical sensor. This is why buck-boost converters became especially popular with the rise of Li-Ion batteries.

There is a similar need when using three primary cell batteries with 1.5 V in series. In total they will provide 4.5 V when fully charged, but when nearly discharged, the batteries only provide roughly 2.4 V. Generating a fixed 3.3 V for the sensor again requires a buck-boost solution.

Figure 2 shows a buck-boost solution with the MAX77837. This solution requires few external components making the required printed circuit board area extremely small. Also, the chip itself comes in a very small package requiring only 1.84 mm × 1.03 mm. If a sensor manufacturer would like to use a package with a larger pitch (distance between the pins), a 2.5 mm × 2 mm QFN package is available.

To make the battery last as long as possible, this solution only requires a quiescent current of 430 nA typical. When shut down, the power conversion IC consumes a mere 10 nA. This may be useful for applications that have an energy storage capacitor next to the main battery. The DC-to-DC converter can then be in a shutdown mode for some period of time before it reactivates and charges the capacitor up again. Such a scheme may provide additional energy saving over time and it may make the operation time with a given battery even longer.

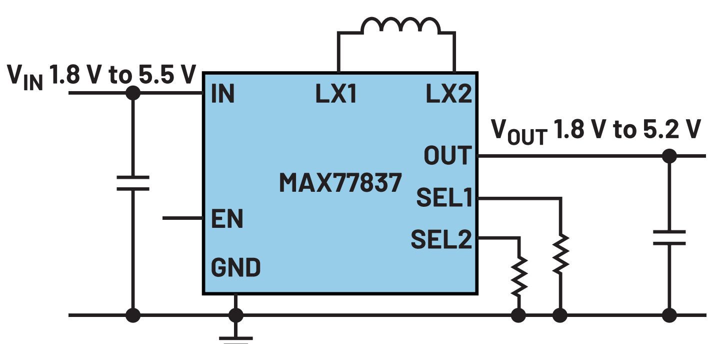

Figure 2. An ultraefficient buck-boost converter to generate a voltage higher or lower than the input voltage.

MAKING DESIGN SIMPLE WITH CIRCUIT SIMULATION

When designing a battery-powered sensor, it's essential to answer basic questions about the capabilities and limitations of the power circuit. Circuit calculation and simulation are valuable at this stage, as they save time and reduce the risk of starting a hardware design with an unsuitable integrated circuit. ADI offers the free EE-Sim®Power Tool to get started. With this tool a user only needs to enter input voltage, output voltage, and current requirements and a suitable circuit is calculated in no time. Figure 3 shows an example of a circuit simulation result within EE-Sim® Power.

Based on this circuit calculation and based on actual external components, circuit simulation can be performed, giving waveforms of different voltages and currents. Advanced simulations such as load step, AC loop, line transient, and efficiency may also be performed.

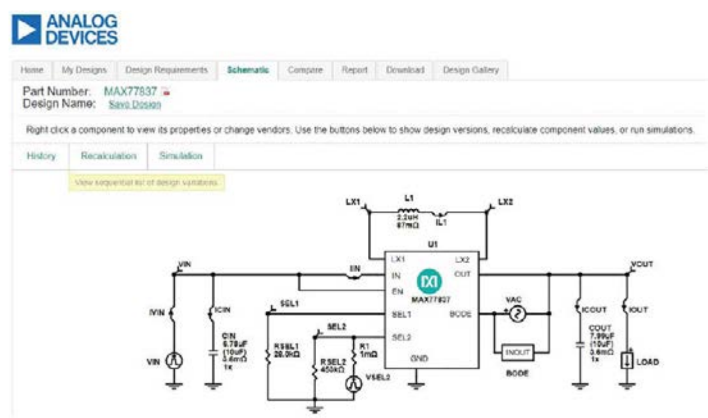

Figure 3. A circuit design and simulation with the EE-Sim® Power Tool.

HARDWARE TO GET STARTED WITH

Theory and simulation are important, but real-world hardware can be quite different. In addition to evaluation boards for individual power converters, there are complete, practical sensor systems available for evaluation. One is the smoke detection system: "Multistandard Micropower Verified Smoke Detection System-on-Module" shows the MAX77837 and the ADP162 to power a complete smoke detector consisting of the ADPD188BI integrated optical module for smoke detection, as well as the MAX32660 with a smoke and fire detection algorithm, and the MAX31875 digital temperature sensor.

All of the design files can be downloaded here, providing an easy path to creating a high quality smart home sensor with nanopower features. This fully optimized and verified sensor hardware includes the necessary software and demonstrates the capabilities of the power management circuitry.

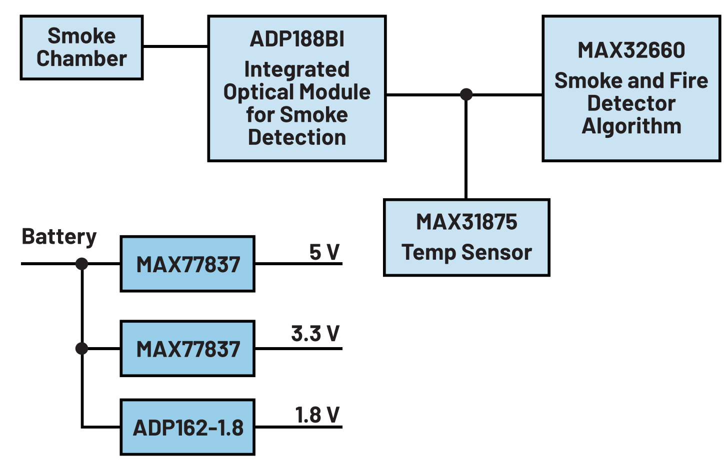

Figure 4. A multistandard micropower verified smoke detection system-on-module.

CONCLUSION

Power management is crucial for enabling the smart home. It ensures highly efficient power conversion, extending the run time of small, low cost batteries. These sensors offer numerous features, including robust connectivity. Today, buck, boost, and buck-boost converters require extremely low quiescent current to make battery or energy harvesting-powered systems practical for many sensor applications. Innovations in semiconductor processes and integrated circuit design make this achievable. Moreover, this is just the beginning; there will be numerous upcoming innovations enabling even smarter sensors in the connected home, all driven by advancements in power management.

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ABOUT THE AUTHOR

Frederik Dostal is a power management expert with more than 20 years of experience in this industry. After his studies of microelectronics at the University of Erlangen, Germany, he joined National Semiconductor in 2001, where he worked as a field applications engineer, gaining experience in implementing power management solutions in customer projects.

During his time at National, he also spent four years in Phoenix, Arizona (U.S.A.), working on switch-mode power supplies as an applications engineer. In 2009, he joined Analog Devices, where he has since held a variety of positions working for the product line and European technical support, and currently brings his broad design and application knowledge as a power management expert. Frederik works in the ADI office in Munich, Germany.

MACHINE LEARNING-POWERED SMART THERMOSTAT ENABLES **INTELLIGENT MANAGEMENT OF HEATING SYSTEMS**

eCozy 2.0 system addresses the limitations of traditional thermostats for water heating radiators, delivering efficiency, convenience and sustainability benefits to households

As global energy prices rise and sustainability becomes a household priority, smart home solutions that balance comfort, efficiency, and environmental responsibility are increasingly in demand. The EU, for example, has published reports showing that sustained high global energy prices are having serious implications for European households, pushing up power bills and creating affordability challenges[1].

Wider research indicates that costs aside, the leading drivers of consumers' smart home purchase decisions are performance, convenience, energy savings, and sustainability[2].

In a global smart home market valued at $84.5 billion in 2024 and projected to reach $116.4 billion by 2029[3], this all adds up to a significant opportunity for innovative developers of energy-efficient solutions.

Traditional thermostats, for example, often fall short in these critical areas. They heat entire homes regardless of whether rooms are occupied, and their rigid schedules fail to account for the unpredictable nature of daily life.

No surprise then that smart products represent 77 percent of sales in the thermostat control market – behind only televisions and robot vacuum cleaners in share of overall sales volume taken by smart products[4].

A SMART THERMOSTAT FOR WATER HEATING RADIATORS

In response to these market conditions and the limitations of existing products, eCozy, a Germany-based company that has twice been awarded the prestigious RedDot Design Award, developed a next-generation smart thermostat for water heating radiators.

By integrating machine learning (ML), Cloud connectivity, and interoperability with emerging smart home standards, the eCozy 2.0 platform empowers users to intelligently manage heating systems, save money, and reduce their carbon footprint.

"The primary benefit of eCozy 2.0 is the significant energy and cost savings – by heating only when and where it is needed the system can reduce heating bills by up to 30 percent, and eliminate the common problem of heating empty rooms or overheating occupied ones," explains Andre Kholodov, CEO of eCozy GmbH.

The eCozy 2.0 system comprises three key components: The smart thermostat device, the central unit (gateway), and the mobile app. The thermostat physically replaces the existing thermostatic head on a water heating radiator. It contains a stepper motor with plunger to open and close the radiator valve, two integrated high-precision temperature sensors, an optional external temperature sensor (via Matter-over-Thread), a high-precision humidity sensor, and a high-accuracy microphone.

The central unit connects to the home's Internet router via Wi-Fi, serving as a gateway to the Cloud and as a Matter controller for seamless smart home integration. The mobile app provides remote management, heating schedule customization, and real-time energy consumption monitoring. Together, these components provide a user-friendly way to create comfort zones in individual rooms.

ENHANCED EFFICIENCY, CONVENIENCE AND SUSTAINABILITY

The eCozy 2.0 solution is designed around enhancing both efficiency and convenience. Users can install thermostats on multiple radiators for zone-based temperature regulation, ensuring each room is heated according to preference. Intelligent heating schedules can be set through the app, allowing users to customize daily and weekly heating routines based on their activities, such as warming up the bathroom in the morning, lowering the heat when they are at work, and ensuring the living room is cozy in the evening.

Remote access is another defining feature, giving homeowners the ability to control their heating systems anytime and anywhere with an Internet connection. The system's open window detection function identifies sudden drops in temperature and temporarily closes the radiator valve to prevent wasting energy by attempting to heat a ventilated space.

Beyond the energy and cost savings, the system enhances comfort and convenience by allowing for tailored room-by-room heating and easy adjustments via the app or any major voice assistant platform like Amazon Alexa, Apple HomeKit, and Google Assistant. For users already invested in smart home technology, eCozy 2.0 integrates seamlessly with other Matter-compatible devices, adding to the overall value of the ecosystem.

By reducing energy use and associated carbon emissions, the system also contributes to environmental sustainability. It offers detailed insight into energy consumption patterns, empowering users to make more informed choices and exercise greater control over expenses as well as environmental impact.

In addition, eCozy 2.0 is designed with longevity in mind. Its long battery life and capability to receive over-the-air firmware updates extend the lifespan of the device and reduce electronic waste. By combining user savings with eco-conscious design, the product contributes to both household efficiency and broader environmental goals.

ENABLING ADVANCED FEATURES AND ML CAPABILITY

At the heart of eCozy 2.0 is the Nordic Semiconductor nRF5340 dual-core multiprotocol SoC. The nRF5340 provides the processing power, wireless connectivity, and ML capabilities that enable advanced smart thermostat features. Many of eCozy 2.0's functionalities are enabled through a combination of on-device ML, powered by the nRF5340 SoC, and advanced AI algorithms running on the eCozy Cloud backend. The system can thereby learn user behavior patterns and optimize heating schedules automatically, detect unusual heating activity or potential issues like a radiator malfunction, and infer room occupancy more accurately for smarter adjustments.

Over time, predictive maintenance capabilities can anticipate potential device issues before failures occur. The integration of the high-accuracy microphone with on-device ML processing allows for advanced acoustic event recognition, such as identifying the sound of a smoke alarm and triggering an immediate alert to the user's smartphone. Moreover, the Nordic SoC supports Matter-over Thread, ensuring that the thermostat is fully interoperable with the latest smart home standards.

Machine learning elevates eCozy 2.0 from a programmable thermostat to an adaptive and intelligent heating system. Personalized comfort is achieved through learning when residents are typically home, away, or asleep, and automatically adjusting heating schedules to match these patterns. "The machine learning capabilities of Nordic's nRF5340 SoC enable a number of our eCozy 2.0 smart thermostat solution's key features and functionalities, such as anomaly detection and adaptive heating schedules," says Kholodov.

"Furthermore, the comprehensive Nordic nRF Connect SDK [Software Development Kit] provides a ready-made, integrated environment with an RTOS [Zephyr], protocol stacks [Matter, Zigbee, Bluetooth LE], hardware abstraction layers, drivers, libraries, and application samples. This saves significant development time compared to building these components from scratch." For households looking to prioritize the combination of comfort, cost-efficiency, and sustainability, eCozy 2.0 delivers a compelling solution that embodies the future of smart home automation.

CONCLUSION

Machine learning is transforming smart thermostats into adaptive, intelligent systems that optimise comfort and energy use in real time. Platforms like eCozy 2.0, powered by solutions such as the Nordic nRF5340, enable faster development of connected, feature-rich designs, helping engineers deliver more efficient, scalable, and future-ready heating solutions.

CLICK HERE

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REDEFINING SMART HOME HUB DESIGN WITH **POWER AND FLEXIBILITY**

Home automation is the technology used to remotely control and manage household systems and appliances, including lighting, climate control, security systems, and entertainment setups.

Its primary purpose is to enhance convenience, improve energy efficiency, and enhance the quality of life within a home. Home automation aims to create a smart home environment where systems and devices can operate autonomously or be controlled remotely. This is achieved through the integration of sensors, actuators, and communication protocols, allowing various elements of the home to work in harmony. For example, lights can be programmed to turn on when someone enters a room, thermostats can adjust the temperature based on time, and security systems can alert homeowners of unusual activity. The goal is to create an environment that is efficient, secure, and responsive to occupant needs.

Home automation (HA) has evolved significantly over the years, with the advent of Wi-Fi, Bluetooth, Zigbee, and Z-Wave protocols making it more accessible and affordable for the average homeowner. The rise of the Internet of Things (IoT) has further revolutionised HA by allowing everyday objects to be connected to the internet, enabling seamless communication and control. Smart home devices like thermostats, lights, locks, and cameras can be controlled remotely via smartphones or voice assistants like Amazon Alexa, Google Assistant, and Apple's Siri.

Advancements in artificial intelligence (AI) and machine learning have added a new dimension to HA, allowing for personalised and adaptive automation. For example, smart thermostats can learn a household's routine and adjust the temperature accordingly, while security systems can differentiate between regular and suspicious activity.

Home automation offers several key benefits that cater to these evolving needs:

- **Convenience and comfort:** Homeowners can control various aspects of their home with a few taps on their smartphone or through voice commands.
- **Energy efficiency:** Optimising the use of household appliances and systems, such as smart thermostats and automated lighting systems, improves energy efficiency.
- **Enhanced security:** Features such as remote locking/unlocking of doors, motion detection, and integration with surveillance cameras enhance overall home security.
- **Improved quality of life:** HA systems create a responsive and adaptable living environment, such as smart home systems for the elderly or disabled, and integrated entertainment systems provide a seamless and immersive experience.

BLOCK DIAGRAM / ARCHITECTURE OF HOME AUTOMATION SYSTEM

A typical home automation system block diagram consists of a central hub (control unit), sensors, actuators, user interfaces, and communication protocols. The central hub is responsible for processing data, executing commands, and managing communication between devices. Common types of sensors include motion sensors, temperature sensors, humidity sensors, light sensors, and door/window sensors. Actuators perform actions based on commands from the central hub, such as smart lights, smart locks, smart thermostats, motorised blinds, and sprinkler systems.

User interfaces allow users to interact with the home automation system through mobile apps, web interfaces, voice assistants, and touch panels. These interfaces enable users to control and monitor the system, send commands, and receive notifications. Communication protocols ensure seamless data exchange between all components, allowing for integration and interaction within the home automation ecosystem.

They enable communication between the central hub and other devices, such as Wi-Fi, Bluetooth, Zigbee, Z-Wave, and MQTT. Sensors detect changes and send data to the central hub via communication protocols, while the central hub processes the data and makes decisions based on pre-set rules or user inputs.

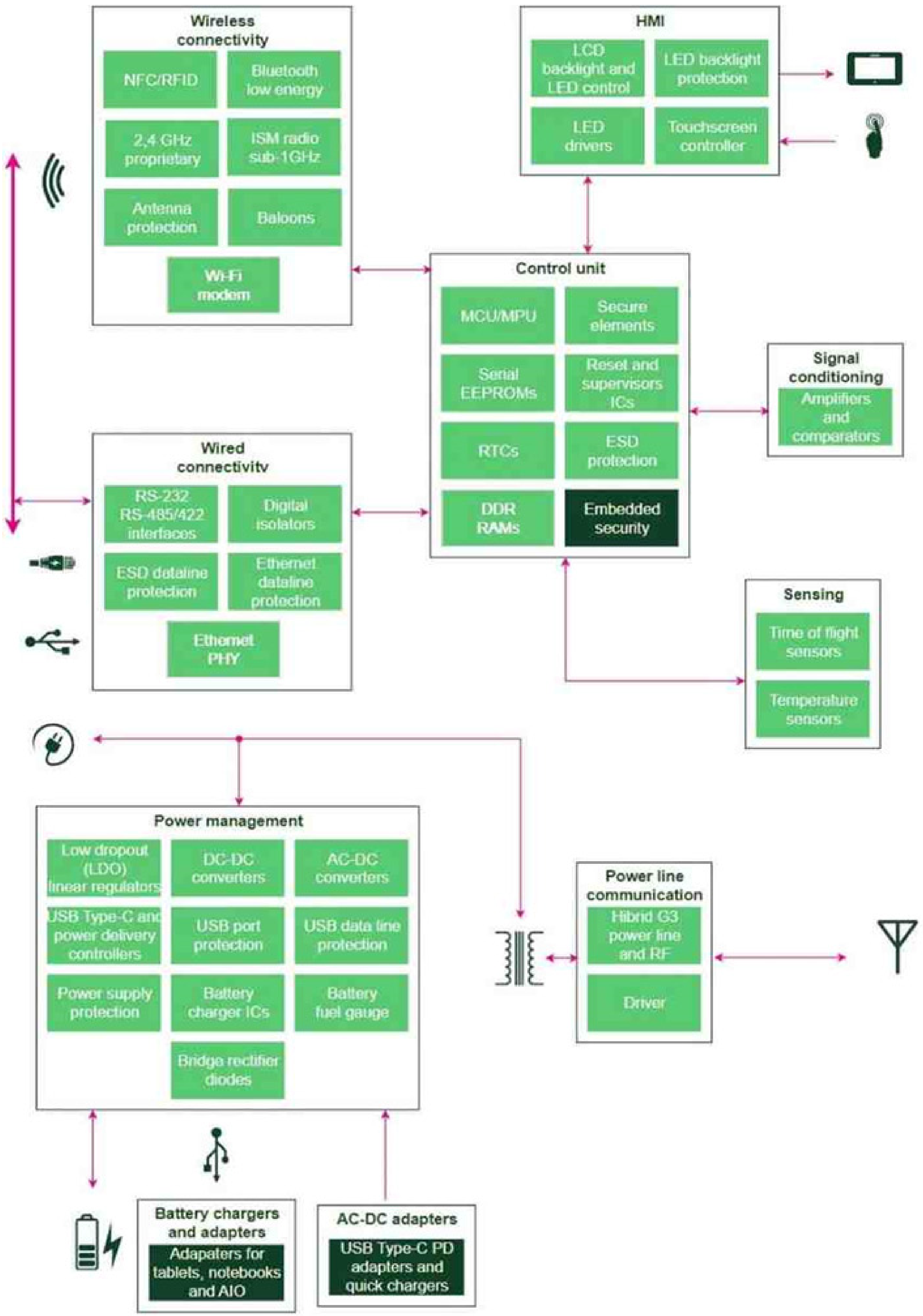
Figure 1 represents the bridge and gateway integration and interaction of various devices within a typical home automation system, illustrating how sensors, actuators, and user interfaces are connected through a central hub and communication protocols.

Home automation requires selecting the right wireless standard for reliable communication, low power consumption, and effective functionality. Key wireless standards include the following technologies:

- Zigbee is a low-power, low-data-rate wireless mesh network standard designed for reliable, scalable, and secure communication for battery-powered sensors. It is suitable for battery-operated devices and supports mesh networking, enhancing range and reliability. However, it requires a dedicated hub or coordinator and has limited data transfer rates.
- Z-Wave is a low-power wireless communication protocol designed for home automation, well-suited for security applications due to its strong encryption and reliable communication, like door/window sensors, motion detectors, smart locks, thermostats, lighting control, and security sensors. It operates on a different frequency than Wi-Fi, offering range and scalability, with mesh networking capabilities being advantageous for larger homes.
- Wi-Fi offers high bandwidth for real-time data transfer, making it ideal for security cameras and video doorbells. Wi-Fi is a widely used wireless networking technology that allows devices to connect to the internet and communicate with each other. It is suitable for home appliances, smart thermostats, security cameras, and smart speakers. However, it has high power consumption and can be less reliable due to network congestion.
- Bluetooth and Bluetooth Low Energy (BLE) are low-power wireless communication standards suitable for wearable health monitors, medical sensors, and security devices like key fobs and door locks. It offers ease of integration, low power consumption, and is ideal for short-range communication compared to Wi-Fi.
- Matter, an emerging standard aiming to unify smart home devices across different platforms and ecosystems, has the potential to simplify device compatibility in the future.
- Thread is an IP-based wireless networking protocol for low-power, secure home automation. It offers direct internet connectivity and mesh networking capabilities.
- LoRaWAN is a long-range, low-power wireless communication protocol suitable for connecting devices in large homes, outdoor areas, or even detached buildings on a property. It is used for wide-area networks, environmental monitoring, smart metering, and security sensors.
- NB-IoT is a cellular communication technology designed for low-power wide-area networks, ideal for IoT applications. It offers extensive coverage, low power consumption, high reliability, and secure communication.

Cloud services offer centralised storage for device data, enabling remote access to sensor readings, automation logs, and user preferences. They can handle complex automation rules and intensive data analysis, reducing the burden on local hubs. However, cloud-based systems raise security and privacy concerns, as sensitive data requires robust measures to prevent breaches.

Sharing data with cloud services raises concerns about user privacy and the potential misuse of information. Cloud reliance depends on a stable internet connection, making it crucial to weigh security and privacy considerations before relying solely on cloud services for home automation. Cloud services enhance automation and decision-making in home automation systems by providing encryption, user authentication, data anonymization, and user control.



HOW RASPBERRY PI CM5 SOLVES THE PURPOSE OF HOME AUTOMATION NEEDS

Raspberry Pi is a compact, powerful computer popular for building versatile home automation solutions due to its compact size, processing power, cost-effectiveness, and open-source ecosystem. The Raspberry Pi Compute Module 5 (CM5), as shown in Figure 2, is a robust System on Module (SoM) that offers significant processing power in a compact form factor. The CM5's integration capabilities make it a versatile hub for managing diverse home automation devices, ensuring cohesive and efficient operation across the entire system. Customisation options allow users to choose the most suitable setup for their specific home automation needs. Compared to other generic home automation hubs, the CM5 offers a highly cost-effective solution, making it an attractive option for hobbyists and professional developers.

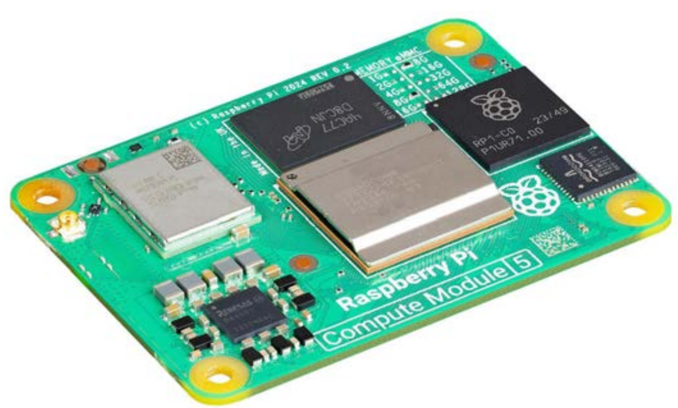


Figure 2: Raspberry Pi CM5 Module

It is ideal for space-constrained and resource-intensive applications. Key features of the CM5 include a quad-core Arm Cortex-A72 CPU, dual video output, and support for various communication interfaces such as PCIe, USB 3.0, and Gigabit Ethernet. Available in 32 variants, with a range of RAM and eMMC Flash options, and with or without wireless connectivity, its quad-core processor delivers substantial computing power, essential for handling complex tasks like processing data from multiple sensors and running machine learning algorithms for smart decision-making. The Compute Module 5 has undergone extensive compliance testing and meets the standards required in many countries.

CMs typically consume less power than traditional Raspberry Pi boards, making them an energy-efficient choice for a continuously running home automation system. The Raspberry Pi ecosystem has an extensive open-source community that provides a wealth of resources, including tutorials, code libraries, and project examples, which can significantly accelerate the development of home automation. Access to these resources ensures continuous updates and improvements, making it an energy-efficient choice for continuous operation.

RASPBERRY PI COMPUTE MODULE 5 IO BOARD

The Raspberry Pi Compute Module 5 IO Board (CM5IO) is an invaluable development tool. CM5IO is designed to assist in the development of products that make use of the Raspberry Pi Compute Module 5. Exposing every interface from the Compute Module 5, the IO Board provides a development platform and reference base-board design for our most powerful compute module yet and is also designed for integration into end products.

The CM5IO has been designed as both a reference design for CM5 and to be used directly as a product with the possible addition of PCIe cards and Raspberry Pi HATs. Figure 3 shows the CM5 assembled over the CM5IO carrier board. Compared to dedicated home automation hubs, the CM5IO offers a cost-effective solution, providing flexibility and potentially saving on upfront costs.

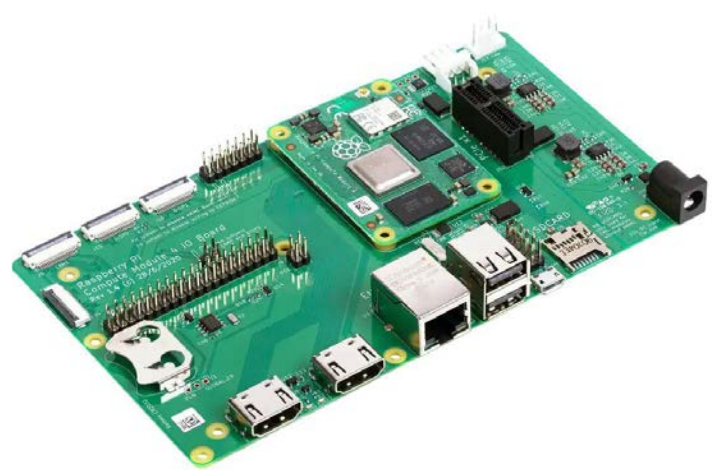


Figure 3: Raspberry Pi CM5IO

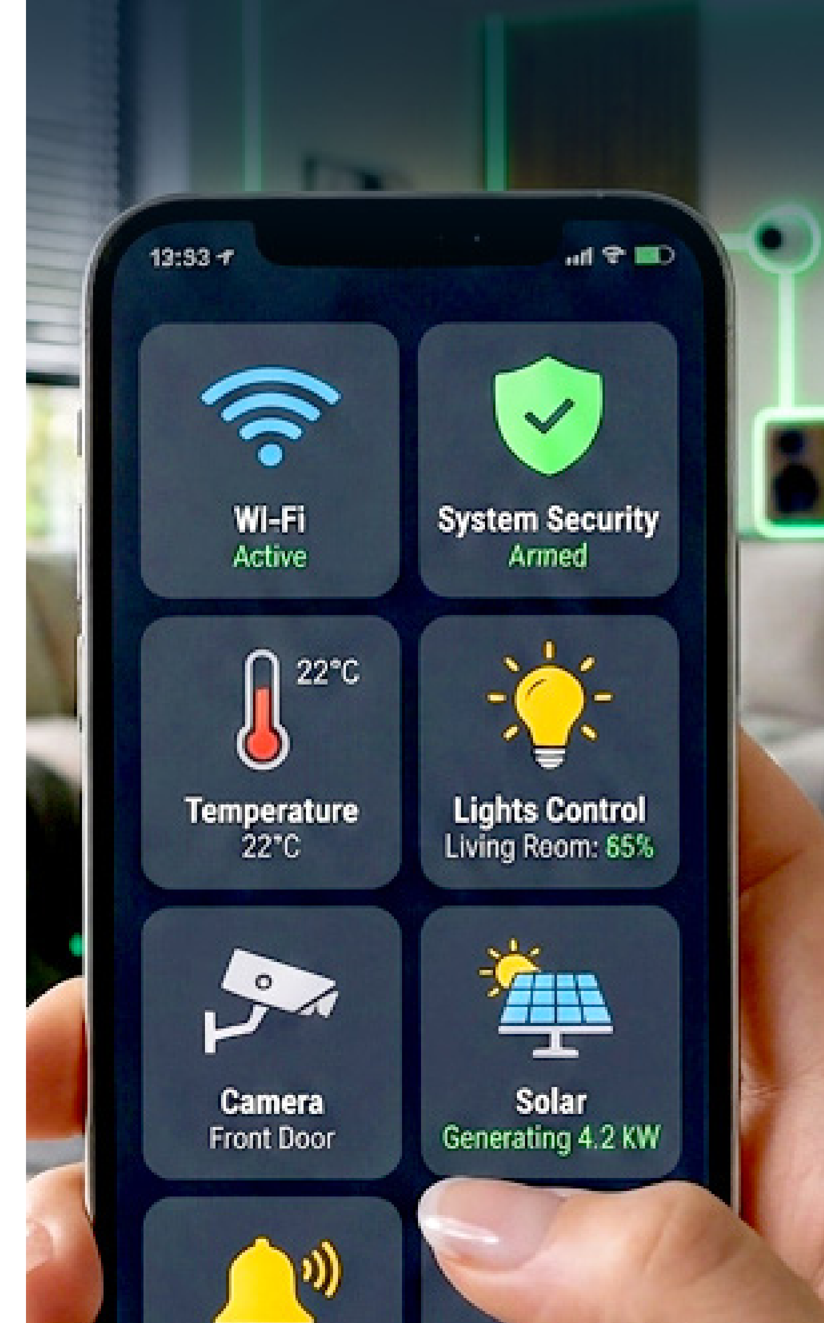
The CM5 single-board computer (SBC) is designed for embedded applications, including home automation. Its small footprint allows for discrete integration into tight spaces and system through carrier boards (CM5IO). Carrier boards often offer expansion options like additional USB ports or SPI interfaces, providing connectivity options such as HDMI, USB, and Ethernet ports, which allow you to connect more sensors and devices to your system as your needs evolve. It is compatible with Raspberry Pi HAT connectors, enabling extended functionalities like relay control, sensor integration, and wireless communication. The CM5 is energy-efficient, consuming less power than traditional Raspberry Pi boards.

HOMEY PRO – AN ADVANCED HOME AUTOMATION HUB

The Homey Pro smart home hub is an advanced device that enhances the functionality and user experience of smart home systems. Powered by the Raspberry Pi CM5, it provides a single interface for controlling and monitoring devices from various brands. The hub operates on the local network, ensuring low latency, reliability, and strict privacy. Users can control their entire smart home from one place using a smartphone app or web dashboard. The flow system allows users to share and publish apps.

The Homey Pro, as shown in Figure 4, is an advanced home automation hub that supports various communication systems such as Zigbee, Z-Wave, Wi-Fi®, Bluetooth, 433MHz RF, Infrared, and Thread. It supports a wide range of devices and can be easily integrated for improved software support. The device also features flow automations for monitoring energy usage by different devices. The Homey Pro Ethernet Adapter ensures reliable wired connectivity, while the Homey Bridge extends wireless coverage throughout the home. Homey Pro operates on-premises for low latency and reliability, with the cloud only used when necessary. Local backups can be saved and managed on a Mac or PC, while cloud backups are available as a paid service. The advanced flow feature allows for automated tasks without additional costs.

HomeyScript is a powerful JavaScript-based scripting language tool for creating personalised tasks for any advanced use case, allowing users to customise their home automation system. It interacts with the Homey Web API and Homey Apps SDK functions, allowing users to control and monitor devices. Homey Pro's Flow feature allows users to create automated sequences and routines without programming skills, triggering flows based on time, location, or device states, providing high and automation for daily routines.



CONCLUSION

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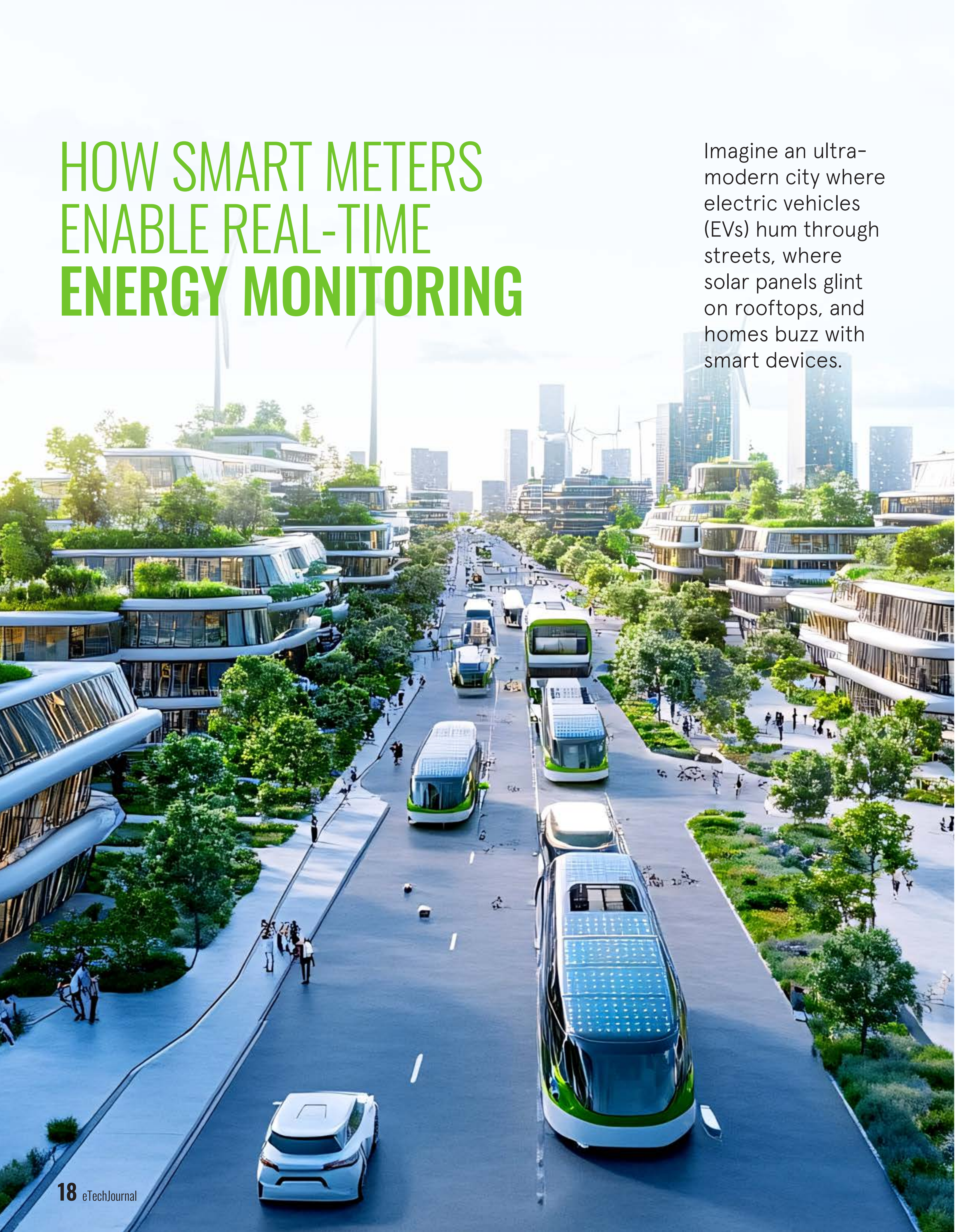
HOW SMART METERS ENABLE REAL-TIME **ENERGY MONITORING**

Imagine an ultra-modern city where electric vehicles (EVs) hum through streets, where solar panels glint on rooftops, and homes buzz with smart devices.



THE PULSE OF A CONNECTED ENERGY FUTURE

To make this dynamic scene possible, you need a quiet powerhouse: the smart meter. These devices silently capture every kilowatt-hour, even the tiniest voltage fluctuation, and every demand spike in real time. Unlike traditional electromechanical meters that show only cumulative totals, smart meters provide detailed insights into how, when, and where energy is used. For design engineers, smart meters enable efficiency, resilience, and sustainability- effectively making them the backbone of smart grids. These meters are indispensable.

This article examines the architecture, protocols, and implementation details of smart metering, offering a technical blueprint for engineers shaping the future of energy management.

WHAT ARE SMART METERS?

Smart meters are advanced digital devices that measure and record real-time utility consumption (electricity, gas, or water), transmitting this data to utilities via wireless or wired networks. Unlike traditional analog meters, which require manual reading and provide only cumulative usage, smart meters offer granular data at intervals as short as 15 minutes. Enabled with wireless IoT connectivity, utilities can collect accurate consumption data remotely and automatically, eliminating manual work. Smart meters enhance real-time data analysis and operational efficiency when integrated with the Smart Meter Operations Center (SMOC) and the broader IoT ecosystem. They play a vital role in Advanced Metering Infrastructure (AMI), enabling two-way communication between utilities and consumers through seamless integration with communication networks and data management systems.

KEY COMPONENTS

- **Metering module:** Employs sensors such as current transformers (CTs) and voltage transformers (VTs) for electricity or ultrasonic sensors for gas and water, achieving high accuracy (e.g., Class 0.5 for electricity, ±0.5% error).
- **Communication module:** Facilitates data transmission using protocols like DLMS/COSEM or IEEE 2030.5 over networks such as Zigbee, Wi-Fi, cellular (4G/5G), or Power Line Communication (PLC).
- **Power supply:** Typically, mains-powered with a lithium-ion backup battery to ensure operation during outages.
- **Microcontroller/Microprocessor:** Handles data processing, often using digital signal processing (DSP) for precise calculations, such as the Texas Instruments MSP430 for metering applications.
- **User Interface (UI):** An optional interface (physical or app-based) that provides consumers with real-time usage and cost feedback.

Smart meters also monitor power quality parameters, such as voltage sags, swells, and total harmonic distortion (THD), which are critical for grid stability. Figure 1 shows the key components of a smart meter.

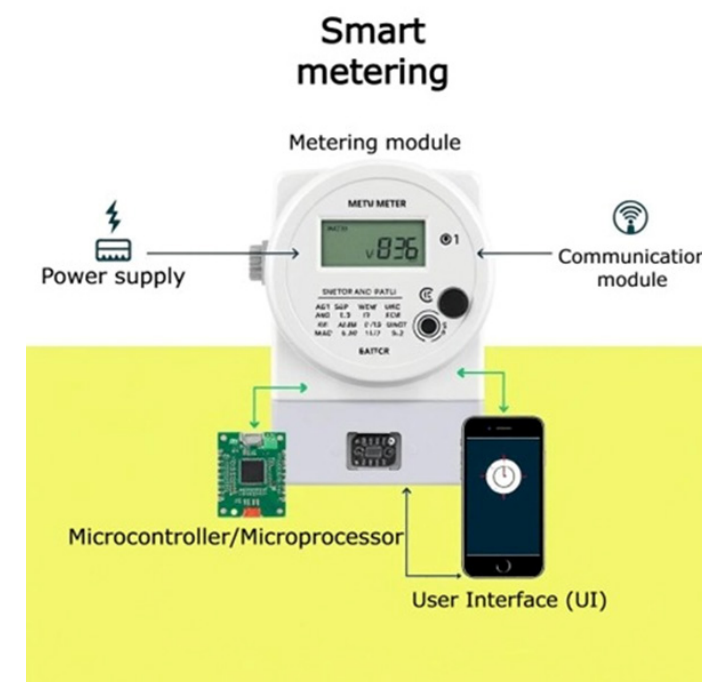


Figure 1: Key components of Smart meter

IMPORTANCE OF SMART METERS

Smart meters play a key role in today's energy systems by supporting smart grids, helping integrate renewable energy, and giving consumers more control over their energy use.

- **Real-time grid management:** Provide utilities with granular data for load balancing, demand forecasting, and outage detection, improving grid reliability.
- **Demand response:** Enable time-of-use (TOU) pricing and demand response programs, encouraging consumers to shift usage to off-peak periods.
- **Renewable integration:** Support distributed energy resources (DERs) like solar panels by tracking bidirectional energy flows, which is critical for net metering.
- **Consumer empowerment:** Offer real-time feedback via IHDs or apps, helping consumers optimize usage and reduce costs.
- **Grid modernization:** Facilitate the transition to smart grids, enhancing efficiency and resilience through two-way communication.

TYPES OF SMART METERS

Smart meters are categorized by utility type and functionality:

BY UTILITY

- **Electricity smart meters:** Measure kWh, voltage, current, and power quality (e.g., total harmonic distortion, THD).
- **Gas smart meters:** Measure gas volume (m^3 or ft^3) using ultrasonic or diaphragm sensors.
- **Water smart meters:** Measure water volume (litres or gallons) with ultrasonic or turbine sensors.

BY FUNCTIONALITY

- **Single-Phase smart meters:** For residential and small commercial applications.
- **Three-Phase smart meters:** For industrial and high-load facilities.
- **Prepaid smart meters:** Embedded with payment logic, enabling users to manage consumption upfront.
- **AMI-Integrated meters:** Advanced Metering Infrastructure-ready, capable of mesh networking and real-time telemetry.

HOW SMART ENERGY METERS WORK TO ENABLE REAL-TIME MONITORING?

Smart meters automatically measure and send your energy usage data to providers every few minutes, helping track consumption and ensure accurate billing. They also detect outages or surges in real time and support features like time-of-use pricing to save costs. Smart meters consist of the following subsystems:

MEASUREMENT

- **Electricity:** CTs and VTs step down high voltage/current for measurement. A 16-bit ADC with DSP calculates power (V × I × cosφ) and energy (kWh), achieving accuracy within ±0.5% (Class 0.5).
- **Gas/Water:** Ultrasonic sensors measure flow velocity, which is converted to volume via algorithms. Accuracy is typically ±1–2%.
- **Power quality:** Meters monitor voltage sags, swells, and harmonics, which are critical for grid stability.

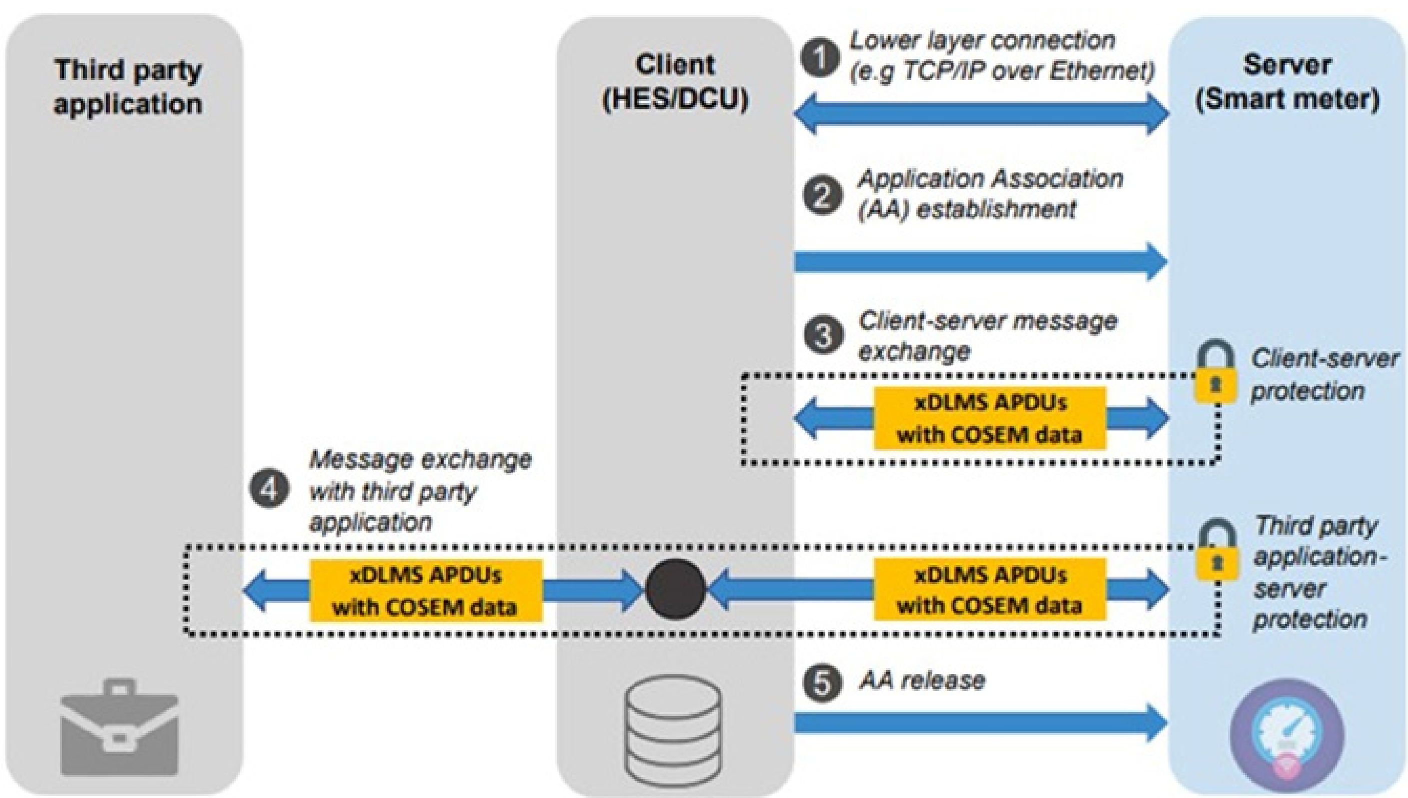


Figure 2: The typical DLMS/ COSEM communication flow

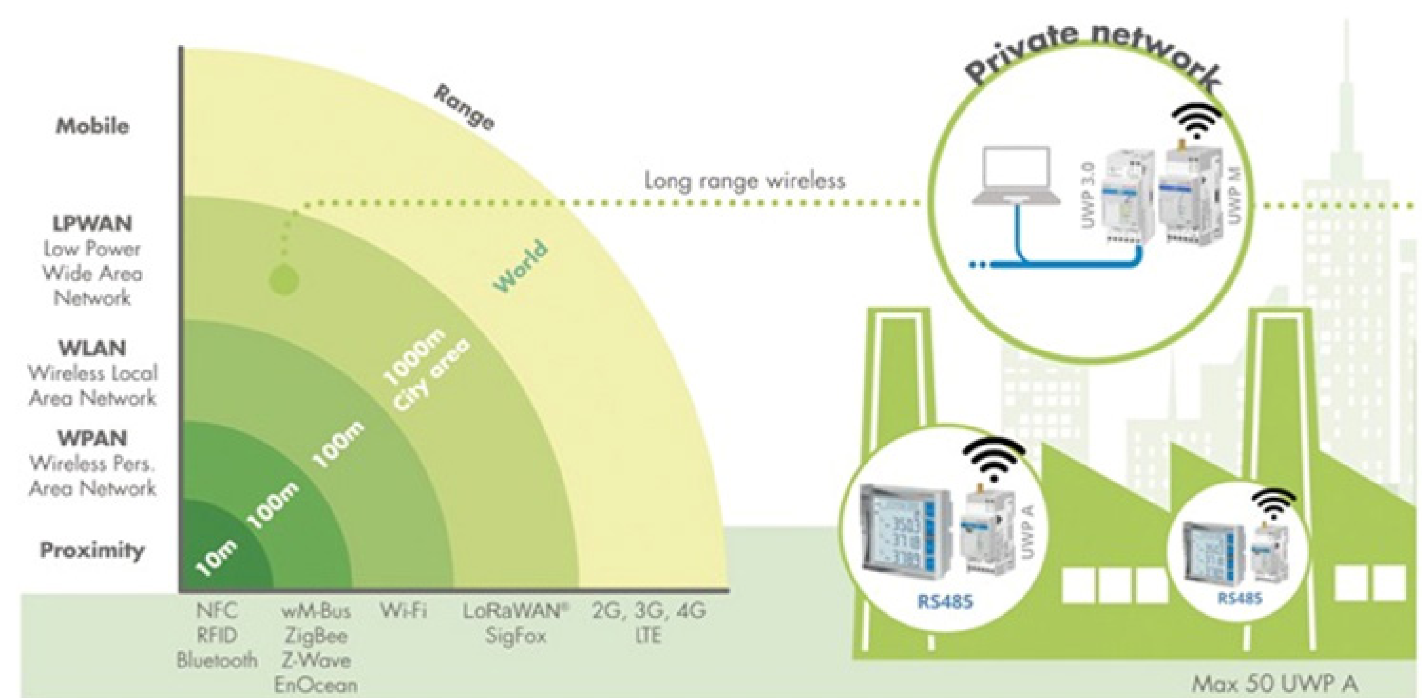
DATA RECORDING

- Consumption data is sampled at intervals (e.g., 15 minutes for electricity, hourly for gas/water) and stored in non-volatile memory (e.g., EEPROM).
- Metadata like timestamps, meter IDs, and diagnostic flags are included.

DATA TRANSMISSION

Smart meters transmit data using standardized protocols and networks.

- **Protocols**
  - » **DLMS/COSEM:** International standard for metering data exchange, using OBIS codes for data identification IEC 62056. Figure 2 illustrates the secure communication process between a smart meter (server), a client system (HES/DCU), and a third-party application using xDLMS APDUs with COSEM data, covering connection setup, application association, message exchange, and release phases.
  - » **IEEE 2030.5:** Supports smart energy profile (SEP2) for Home Area Network (HAN) integration IEEE 2030.5.
  - » **Modbus:** Used in industrial applications for meter-to-PLC communication.
- **Networks**
  - » **Zigbee:** Low-power, mesh-based protocol for HANs, with 250 kbps data rate and 100m range.
  - » **Wi-Fi:** High-bandwidth option for urban areas, supporting OTA firmware updates.
  - » **Cellular (4G/5G):** Ideal for remote locations, with NB-IoT or LTE-M for low-power wide-area networks (LPWAN). Figure 3 illustrates how various wireless communication technologies—from short-range Bluetooth to long-range LPWAN—connect industrial smart meters (via RS485 and UWP modules) to a centralized private network for scalable energy monitoring.
  - » **PLC:** Uses power lines for data, with standards like G3-PLC offering 33.4 kbps.



- **Data reception and processing**
  - **Headend system:** Aggregates data via a secure gateway using protocols like MQTT or HTTPS.
  - **Meter data management system (MDMS):** This system processes data for billing, analytics, and grid management, often using cloud platforms like AWS IoT.
- **Consumer interaction**
  - UI or mobile apps display real-time usage (kWh, cost) and historical trends, often via Zigbee or Wi-Fi.
- **Implementation details**
  - **Microcontroller:** Typically, a 32-bit MCU (e.g., STM32 or NXP i.MX RT) with 256 KB flash and 64 KB RAM for data processing and protocol handling.
  - **Sampling rate:** Electricity meters sample at 4–8 kHz to capture harmonics up to the 40th order, per IEC 61000-4-7.
  - **Power consumption:** The metering module consumes <1W, critical for battery-powered gas/water meters.
  - **Environmental resilience:** Operates in -40°C to +85°C, with IP68 rating for water meters.

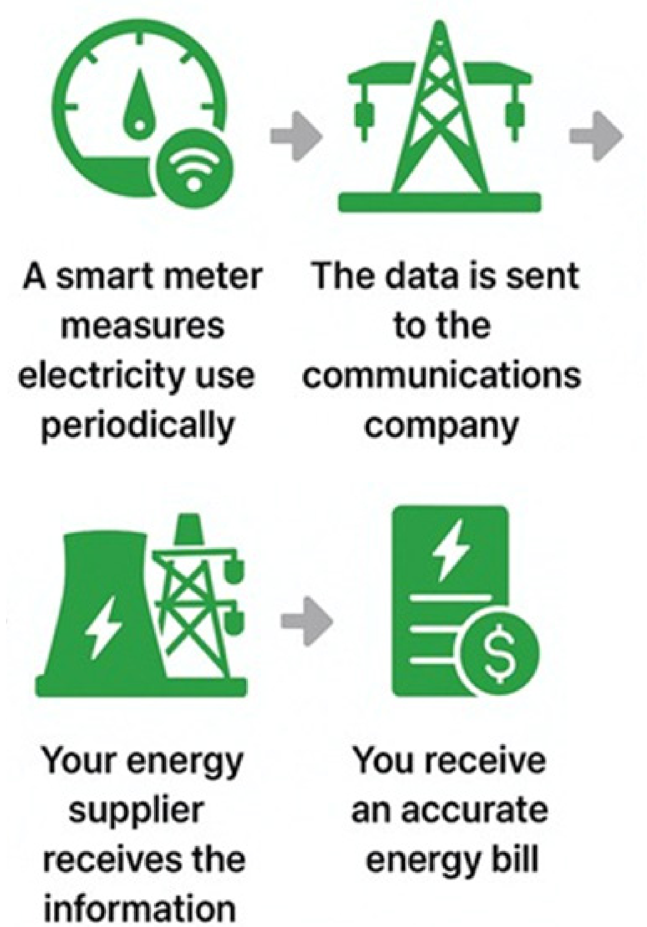


Figure 4: Working procedure of a smart meter

BENEFITS OF SMART METERS

Smart meters benefit utilities with accurate billing, faster outage detection, and improved grid efficiency, while giving consumers real-time insights, cost control, and billing transparency. They also promote energy savings and support renewable integration for a greener grid.

For example, smart metering in EV charging allows precise tracking of energy used per session, supports dynamic pricing and load management, and integrates with utility demand response systems. When combined with communication platforms, revenue-grade meters enable site owners to fairly allocate charging costs, monitor real-time usage, and optimize charging schedules for better efficiency and scalability.

To know more about implementing smart metering in EV charging, click here.

Benefit	Utility impact	Consumer impact	Environmental impact
Billing	Eliminates estimates	Transparent costs	N/A
Efficiency	Cuts labor costs	10–20% bill savings	Reduces emissions
Outage Management	Seconds to detect	Faster restoration	N/A
Renewable Integration	Supports DERs	Enables net metering	Promotes clean energy

Table 1 : Benefits of using smart meters

DESIGN CONSIDERATIONS FOR SMART METERING SYSTEMS

Engineers designing smart metering systems must address several technical challenges:

- **Accuracy:** Meet standards such as IEC 62053-21 (Class 1) or ANSI C12.20 for electricity, ensuring ±0.5% accuracy.
- **Interoperability:** To avoid vendor lock-in, support multiple protocols (e.g., DLMS/COSEM, Modbus) and vendor systems.
- **Scalability:** Handle thousands of meters with low latency (e.g., <1s for outage alerts) using efficient network topologies.
- **Power efficiency:** Minimize consumption (e.g., <1W for the metering module) for battery-powered gas/water meters.
- **Environmental resilience:** Operate in temperatures between -40°C and +85°C, withstand high-humidity conditions, and offer IP68 ratings water meters.
- **Cost:** Balance features with affordability, targeting $50–$100 per meter to ensure mass adoption.

SMART METER TRENDS RESHAPING TOMORROW

Advanced technologies and growing security demands are pushing smart meters beyond simple consumption tracking toward intelligent, interconnected energy management systems. Four major trends are driving this transformation.

- **AI and predictive analytics:** AI and machine learning enhance smart meter functionality by enabling predictive analytics and proactive grid management. These systems forecast demand, detect anomalies, and anticipate equipment failures using models like neural networks and gradient-boosted trees. Utilities can take advantage of this data for dynamic pricing and optimized load distribution, improving grid efficiency.
- **Blockchain for energy transactions:** Blockchain ensures secure, decentralized peer-to-peer energy transactions, supporting transparent billing, prosumer settlements, and microgrid trading. Ethereum-based smart contracts can automate net metering and validate bidirectional energy flows, enhancing trust and data integrity while reducing fraud risks.
- **Integration with IoT and Smart Grids:** Smart meters now function as IoT edge devices within smart grids, communicating in real-time via protocols like MQTT and CoAP. They coordinate with HEMS, EV chargers, and DERs to support demand-side management, voltage regulation, and predictive maintenance through digital twins and software-defined updates.
- **Privacy and Security:** To address growing data privacy concerns, smart meters incorporate AES-128/TLS encryption, secure boot, and hardware root-of-trust. Techniques like differential privacy and federated learning protect data locally, while standards such as IEC 62351 and compliance with GDPR/NIST frameworks ensure end-to-end cybersecurity.

CONCLUSION

Smart meters enable real-time monitoring, accurate billing, and smarter grid management, forming a critical foundation for modern energy systems. As they evolve with IoT, AI, and advanced communication technologies, they support more efficient, scalable, and sustainable power networks. For more such useful knowledge hub information, visit Technical Resources.

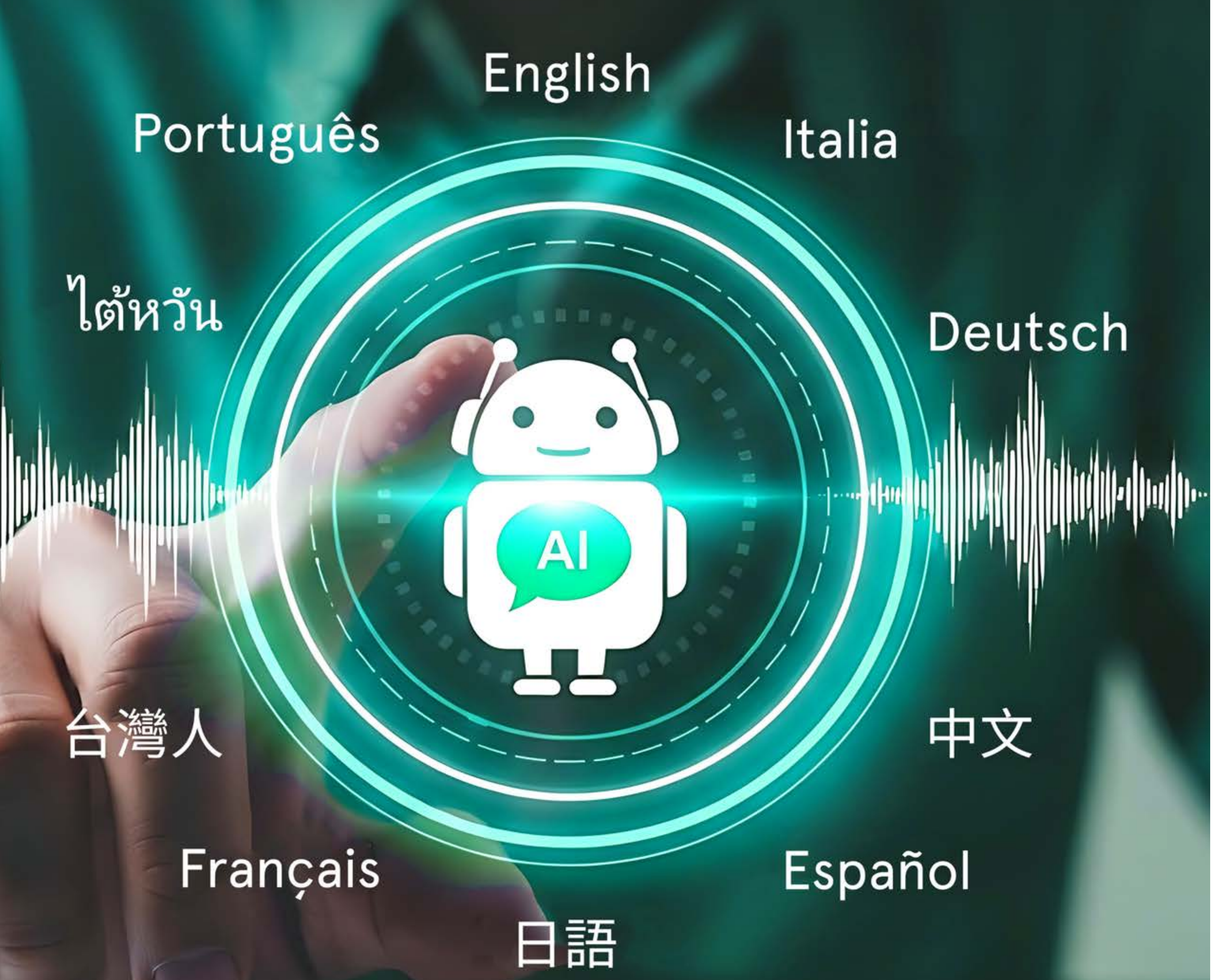
CLICK HERE

READ MORE ON:

- How to implement Smart Metering in EV charging
- Smart Energy Management Systems (EMS) in Smart Buildings
- Energy storage solutions in smart buildings
- Uninterruptible power supply (UPS) systems for critical-loads in smart buildings

BUILDING A **VOICE-ACTIVATED AI** HOME AUTOMATION ASSISTANT ON ARDUINO® UNO™ Q

VISIT ARDUINO



Home automation has come a long way from simple timers and remote-controlled lights. Today, the convergence of AI, IoT, and embedded computing allows even palm-sized boards to serve as intelligent hubs capable of voice interaction, smart device management, and sensor monitoring. In this tutorial, we'll explore how to build a **voice-activated AI assistant** entirely on the **Arduino UNO Q**, integrating multiple smart home protocols, environmental sensors, and audio-visual feedback.

OVERVIEW

The goal is to create a single-board home automation system that can:

- Respond to the wake phrase "Hey Arduino."
- Conduct bidirectional voice conversations using **Google Gemini**.
- Control smart devices across **WiZ bulbs, Samsung TVs, and Matter-compatible Sonoff plugs**.
- Display **audio-reactive LED animations.**
- Monitor **temperature and button inputs**.
- Run scheduled automations.

The Arduino UNO Q's dual-processor architecture — a quad-core Linux MPU alongside an STM32 real-time MCU — allows the system to split tasks efficiently: the MPU handles networking, AI inference, and containerized applications, while the MCU manages real-time LED updates, sensor polling, and button input debouncing. The two communicate via MessagePack RPC over a Unix socket for seamless integration.

SYSTEM ARCHITECTURE

The design consists of **four communication layers**:

1. BROWSER MODE

A responsive web interface connects via **WebSocket** to a **FastAPI** backend running in Docker. Audio captured at **16kHz** from the browser is streamed to Google Gemini's Live API, which responds at **24kHz**. Sensor data, device states, and tool call results flow through the same channel, enabling real-time monitoring and control.

2. HEADLESS MODE

When no browser is connected, a **USB speakerphone** (e.g., Jabra Speak 710) provides the audio interface. Microphone input is captured via **ALSA arecord**, and AI responses are played back with **aplay**. Audio levels are streamed to the STM32 MCU at **45Hz**, driving LED animations in sync with the conversation.

3. MCU COMMUNICATION

Python scripts send **MessagePack RPC commands** over a Unix socket to the Arduino Router service, which relays instructions to the STM32 MCU via a dedicated serial link. The MCU is responsible for:

- LED matrix rendering
- Button state monitoring
- Temperature readings

Audio-Reactive LED Matrix

One of the most visually striking features is the audio-reactive LED matrix. The 8x13 blue LED grid renders three distinct states:

1. **Blank (idle)** – when the system is waiting.
2. **Dim center track (wake word standby)** – indicating readiness.
3. **Combined wave + KITT scanner animation (voice active)** – dynamically visualizing audio input.

The animation composites multiple layers:

- **Multi-frequency sine wave:** Generates organic undulations driven by the audio amplitude.
- **KITT-style scanner:** Sweeps back and forth across the matrix, with tail length increasing as audio intensity rises.

This combination provides an engaging visual representation of voice interaction, making the system not just functional but also visually dynamic.

4. SMART HOME CONTROL

The system interfaces with smart devices using three distinct protocols:

- **WiZ bulbs:** UDP communication via the pywizlight library.
- **Samsung TVs:** WebSocket control via samsungtvws.
- **Sonoff plugs:** Matter protocol through chip-tool over SSH (managed with Paramiko).

This approach allows seamless, multi-protocol smart home control from a single embedded board.

HARDWARE SETUP

MODULINO NODE CONNECTIONS

The Modulino ecosystem provides plug-and-play I2C modules using QWIIC connectors:

1. Connect the Modulino Thermo to the UNO Q's QWIIC port.
2. Daisy-chain the Modulino Buttons to the Thermo.
3. Daisy-chain the Modulino Pixels to the Buttons.

The I2C bus (Wire1 on the UNO Q) handles all three modules at default addresses, requiring no soldering or breadboarding.

USB Peripherals

Connect your USB speakerphone and webcam to the UNO Q via the USB-C hub:

- The app auto-detects the first USB audio device at startup.
- The webcam is accessible via v4l2.

Smart Home Devices

- **WiZ Bulb:** Connect to the same Wi-Fi network as the UNO Q and record its IP for configuration.
- **Sonoff MINIR4M:** Commission as a Matter device using chip-tool and note the node ID.
- **Samsung TV:** Enable Wake-on-LAN and record IP and MAC addresses.

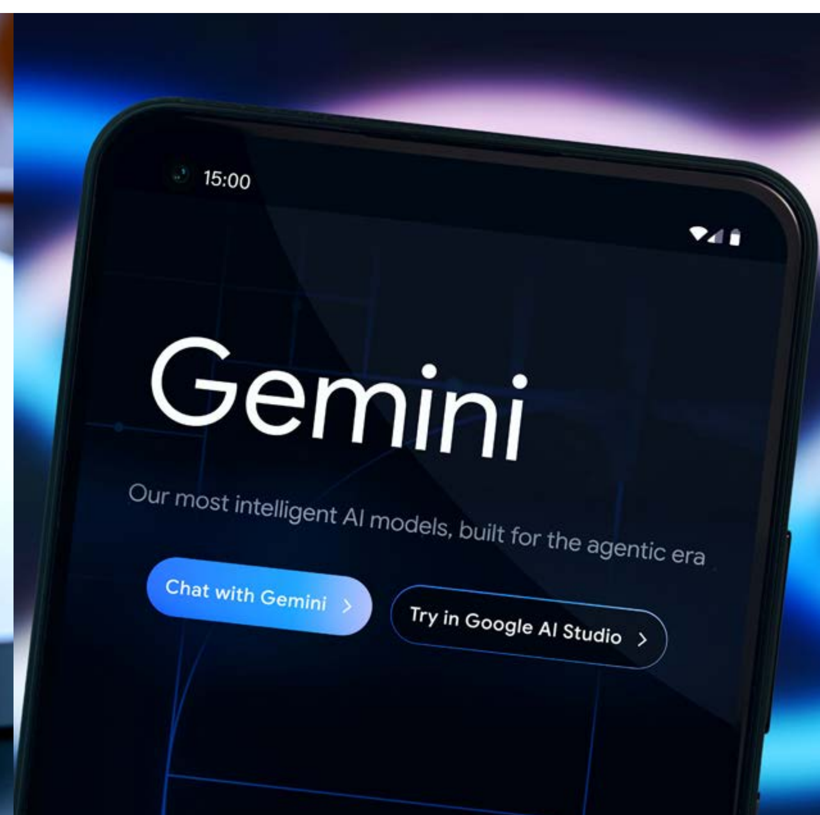
SOFTWARE SETUP

PREREQUISITES

Ensure your UNO Q is network-enabled (Wi-Fi configured via nmcli) and that you have a **Google Gemini API key**. Install the following software tools:

- samsungtvws – Samsung TV WebSocket control
- ddgs – DuckDuckGo search integration
- OpenCV (headless) – For camera processing
- Arduino App Lab – For MCU code development
- Google GenAI SDK – Google Gemini API client
- chip-tool – Matter device commissioning
- pywizlight – WiZ bulb control
- FastAPI + Uvicorn – Web server backend
- Paramiko – SSH communication
- Python 3.11+ – Runtime environment

Once installed, configure your .env file with device IPs, Matter node IDs, and Google API credentials.



BRINGING IT ALL TOGETHER

With the hardware connected and software configured:

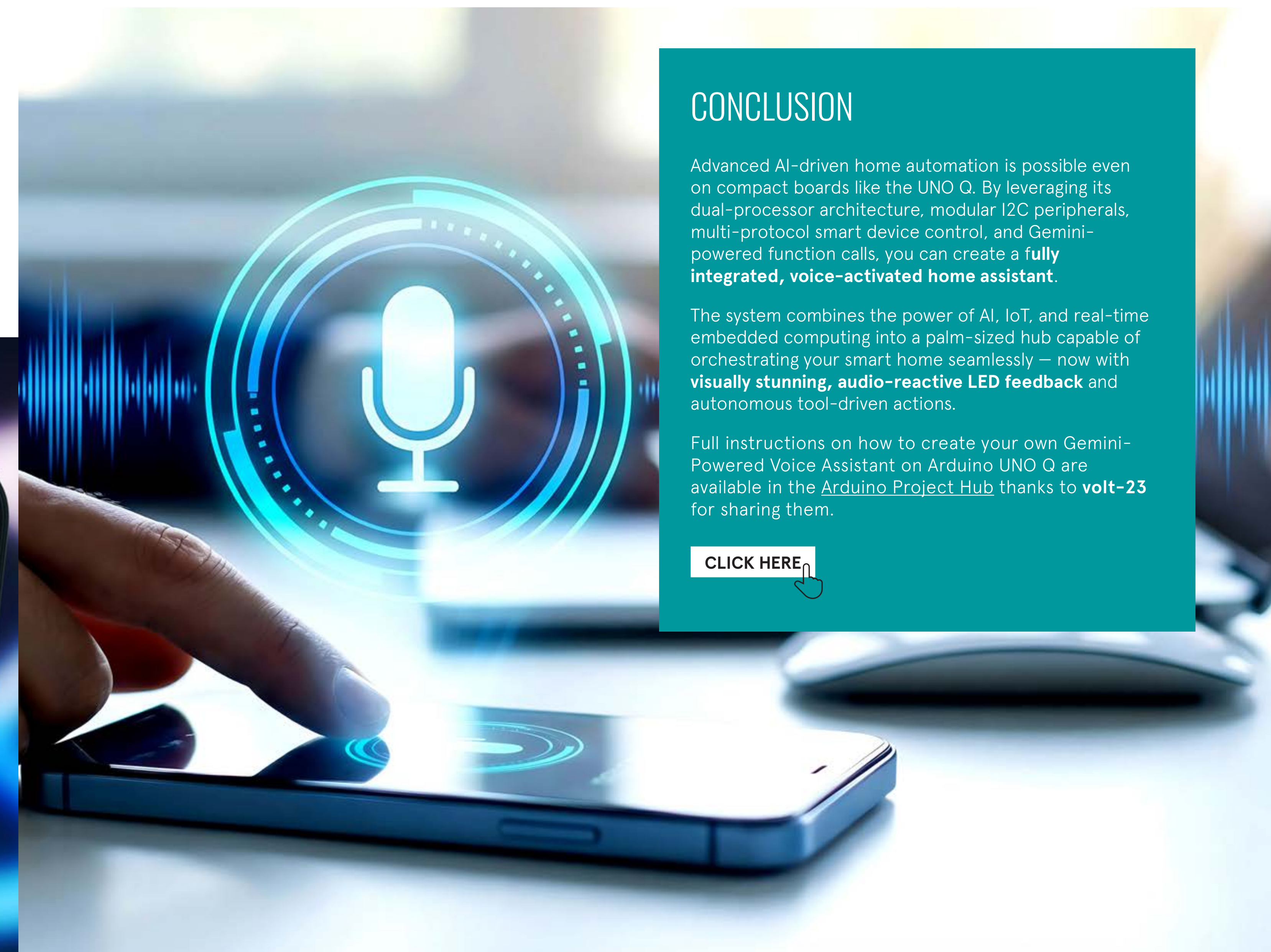
1. Launch the FastAPI backend in Docker.
2. Connect your browser to the web UI or use the headless USB speakerphone mode.
3. Test voice commands:
   » "Turn on the living room WiZ bulb."
   » "Switch off the TV."
   » "What's the temperature in the room?"
4. Watch the audio-reactive LED matrix dynamically respond to your voice.
5. Schedule automations or run custom scripts directly from the UNO Q.

AI FUNCTION CALLS AND PHYSICAL INTERACTION

The AI assistant is not limited to conversation. Through Google Gemini's function calling, it can directly interact with the physical world.

- **Tool Declarations (gemini_tools.py):** Each tool is defined as a types.FunctionDeclaration with a name, description (which Gemini uses to determine when to call it), and a parameter schema.
- **Tool Dispatching (tool_handlers.py):** Gemini calls are dispatched to corresponding Python handlers that interact with smart devices or internal services.

This approach allows your AI assistant to perform context-aware actions autonomously — from toggling lights and adjusting temperature to activating complex sequences across multiple devices.



CONCLUSION

Advanced AI-driven home automation is possible even on compact boards like the UNO Q. By leveraging its dual-processor architecture, modular I2C peripherals, multi-protocol smart device control, and Gemini-powered function calls, you can create a **fully integrated, voice-activated home assistant**.

The system combines the power of AI, IoT, and real-time embedded computing into a palm-sized hub capable of orchestrating your smart home seamlessly — now with **visually stunning, audio-reactive LED feedback** and autonomous tool-driven actions.

Full instructions on how to create your own Gemini-Powered Voice Assistant on Arduino UNO Q are available in the Arduino Project Hub thanks to **volt-23** for sharing them.

CLICK HERE