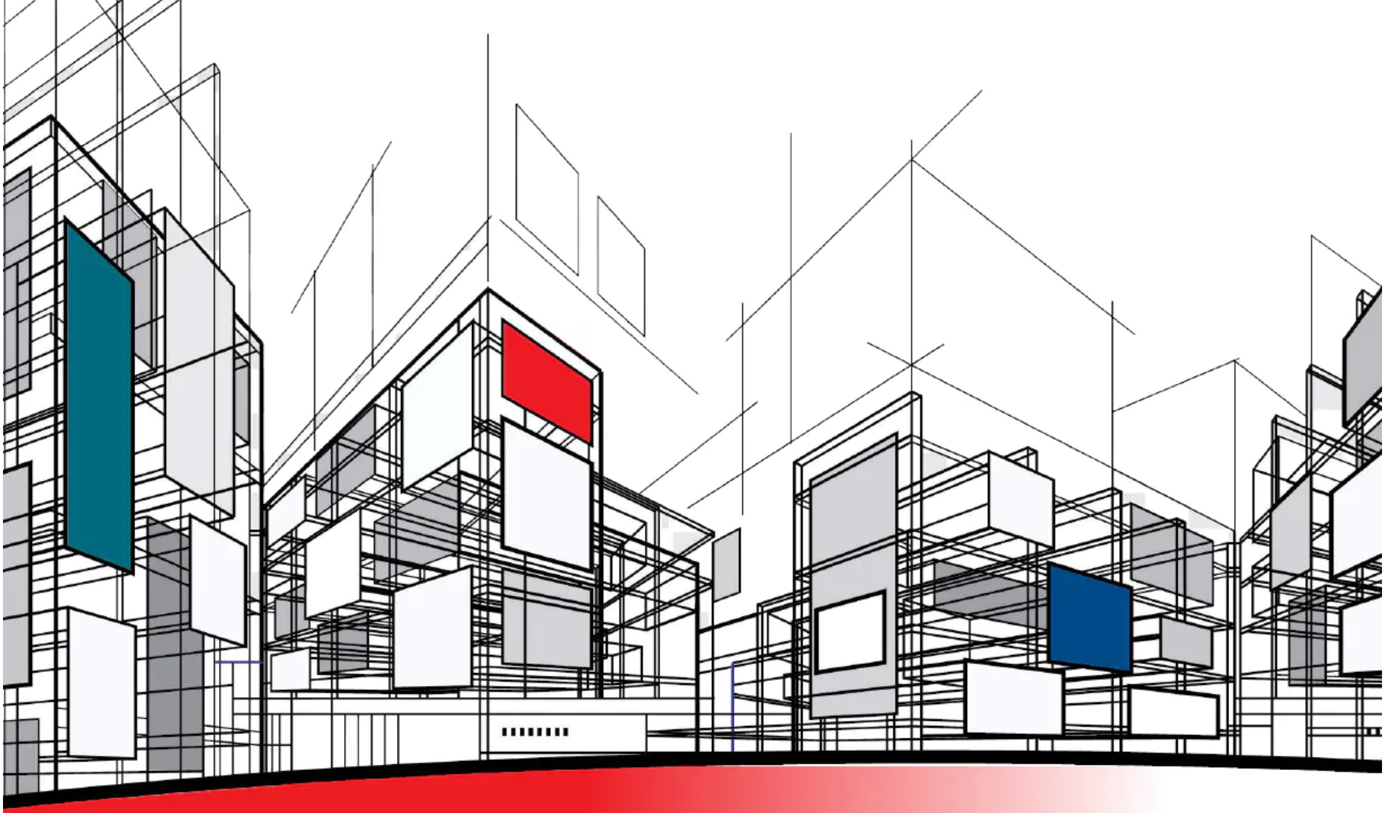
TEXAS INSTRUMENTS

BUILDING AUTOMATION:

TECHNOLOGIES AT THE FOUNDATION OF SMART HOMES AND BUILDINGS



- BUILDING SECURITY SYSTEMS
- VIDEO SURVEILLANCE
- BUILDING LIGHTING
- ELEVATORS & ESCALATORS

MOUSER ELECTRONICS

Table of Contents

3 Foreword

4 Self-Control: Technology at the Foundation of Building Automation

7 Designing the Elevators of the Future

9 Enabling the Next Generation of Video Doorbells

15 Extending Battery Life in Smart Locks

20 Smart Connected Lighting and the IoT

26 No, It's Not a Ghost: AI in Lighting

CONNECT WITH MOUSER

Foreword: Engineering smarter buildings

By Apoorva Awasthy, Texas Instruments

Smarter sensing, increased energy efficiency and wireless connectivity everywhere are just a few of the features driving the latest building automation trends. Designers are facing a strong demand to create safe, efficient and enjoyable building environments. Building automation and home security technologies have transformed from a niche luxury to a suite of viable solutions accessible to most households.

Designing these smarter buildings starts with a sensor node that can detect physical parameters in everyday applications and these nodes are often connected to Internet of Things-related applications. Previously, these nodes send unfiltered data through networks to the cloud for post processing. But now, designers are moving to processing 'at the edge', which means sensor node can process data locally and only needs to utilize the cloud when absolutely necessary. This leads to reduce cost, latency and network bandwidth. Popular building automation applications, such as smart locks, video doorbells and IP network cameras, can benefit from this intelligence at the edge. For example, instead of alerting the user every time there is motion detected, the video doorbell can use its camera as a secondary validation to locally determine if the motion is real before notifying the user remotely using the cloud.

Most connected applications require architectures that can increase battery life by reducing system standby power consumption. This is a key challenge for designers because of the demand for power-intensive processing features such as motion alerts, video analytics, two-way audio communications and noise cancellation that many connected applications for buildings require. If the consumer experiences product downtime due to dead batteries or gets tired of changing the batteries too frequently, they will likely choose to not use the product.

Texas Instruments has design resources and devices specific to building automation applications such as HVAC, building security, video surveillance and more. Our system expertise and large selection of reference designs gives us the competitive advantage to enable our customers to design modern buildings of the future. ■

Apoorva Awasthy, General Manager - Building automation systems at Texas Instruments

Apoorva Awasthy is the general manager for TI's building automation and electronic point of sale sector team. Apoorva has over 20 years of industry experience and leads a team that that creates differentiated reference designs and technical content solving system design challenges. He is known for his expertise in building security systems, HVAC, industrial motor drives and more.

Self-Control: Technology at the Foundation of Building Automation

Paul Golata,
Punya Prakash,
Bryan Trinh,
Texas Instruments

Make Your Bed Every Day

Navy Admiral William H. McRaven (1955–) delivered the commencement address to the graduates of The University of Texas at Austin on May 17, 2014. In his speech, McRaven made the point that "if you want to change the world, make your bed every day."

You see, as a US Navy SEAL, McRaven learned that every day his bed would get inspected by his superiors. It had to be perfect. Making the bed was a simple and mundane task. But that is precisely the point. His superiors knew that how one performed the ordinary and straightforward over-and-over was an insight into how they would perform on more challenging tasks. Completing one simple task well leads to completing the next and other assignments well. It is a reinforcement of positive behavior. And if nothing else goes well that day, at least you come home to a well-made bed. If you want to change the world, start by making your bed.

Self-Control

To date there is no automatic way to make your bed. Making your bed every day is an act of personal self-control. However, technology is rapidly changing the situation of automation within buildings, enabling the building to have self-control over a gamut of internal items. Technology is at the foundation of building automation. In a manner of

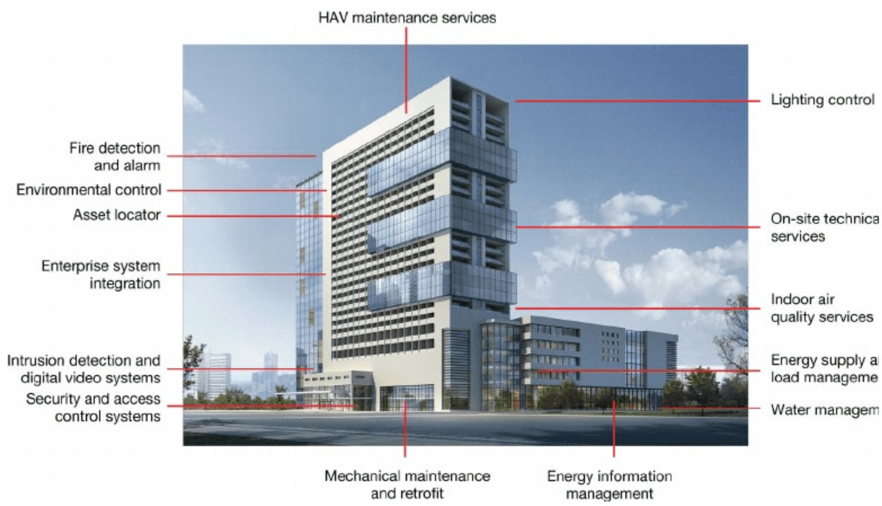


Figure 1: Building Automation System (BAS). (Source: Texas Instruments)

speaking, technology is giving buildings the self-control to “make their beds.” The building’s internal items include lighting control, on-site technical services, indoor air quality services, energy supply and load management, water management, energy information management, mechanical maintenance and retrofit, security and access control systems, intrusion detection and digital video systems, enterprise system integration, asset location, environmental control, fire detection and alarm, and HAV maintenance services (**Figure 1**).

Building Automation Systems

Building Automation Systems (BAS) are now getting deployed across all levels, ranging from small building segments to larger building establishments. BAS are allowing them to be self-controlled utilizing intelligent automation of their control systems. A wide range of solutions from Texas Instruments is making this possible.

In the United States, commercial buildings contribute to approximately forty percent (≈40%) of energy consumption. Present building construction technology advances have facilitated building management with relatively low energy consumption. With the increasing susceptibility of the electricity grid to power outages, building owners are investing in automation of the network of building systems.

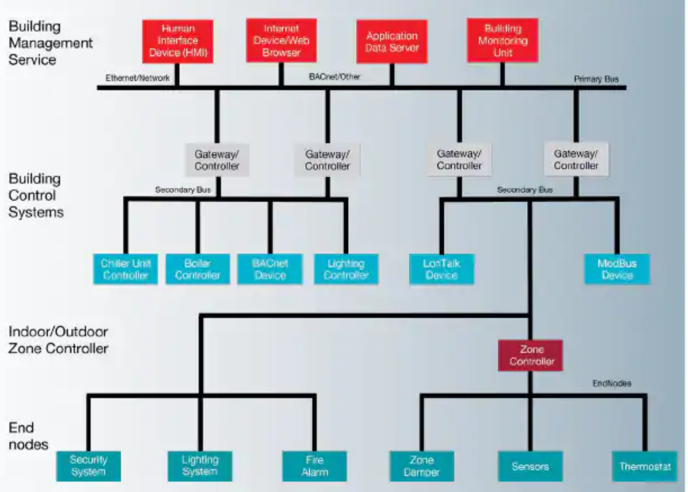


Figure 2: Typical BAS topology (Source: Texas Instruments)

Such a network helps to realize reduction in energy costs. These systems deliver self-sufficiency, improving the overall operational efficiency.

BAS is a communication network infrastructure that manages multiple building services. Key to a capable BAS is having a ubiquitous system that can be deployed to serve new and old building technology as well as small and large commercial facilities. With such well-established automated solutions, competent energy management can get achieved through building-to-building communication rather than just building-to-grid communication.

Building Management Service

Building Management Service (BMS) is a recurring expense. While automated systems could supervise regular building services, they could also get designed for failure detection and essential fault diagnosis. Early detection and well-recorded system data could effectively contribute to enhanced operational performance. The data collected through connected systems can also be used to improve an occupant’s lifestyle, providing a green, convenient, safe work and living environment. Additionally, the comfort and safety of building occupants get managed through a complex network of devices. These devices offer demand-based services that manage essential amenities such as air conditioning and lighting control.

Topology

Typically, the complex building automation network of devices includes a primary and secondary bus that gets connected to various nodes in the system:

- Building Management Service (BMS)
- Building Control Systems (BCS)
- Zone controllers
- End nodes

BMS units host the application and data server. In addition to the servers, they are equipped with a user interface for data monitoring and control. The primary bus, connected to the BMS is the BCS (**Figure 2**). These back-end control systems are centralized and interlinked network of devices that monitor and control the environment. Such control units get specifically designed for building automation and could support single or multiple network and communication protocols.

The primary and secondary bus might get connected to the devices such as:

- Low-level controllers
- Simple input/output devices
- End-user applications such as a room thermostat or local alarm monitoring system

The primary and secondary bus could be RS-485, Ethernet, CAN, or a wireless network.

The applications in an end-node network of a BAS could be a security surveillance unit or a fire alarm system. It could also be an alarm system relaying arm/disarm information to the BMS units. An indoor or outdoor zone controller could be used to monitor and control the systems, calling for cooled or heated air as needed.

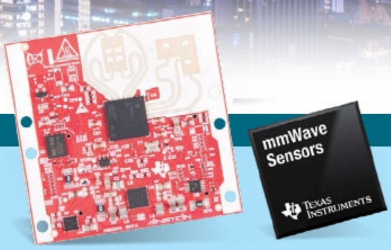
System Energy Automation

BAS primary role is to bind the various systems and devices in a given facility. By connecting individual building elements, it provides a centralized core that can get managed from a main supervisor. This communication network infrastructure ensures reliable data transfer and logging.

By supporting various wired and wireless protocols in a BCS, a scalable bridging platform that can access and control end nodes based on different protocols can get deployed. While significantly improving the operational efficiency, these systems could also be used to ascertain reliability. In addition to lower operational and energy costs, use of data logging and cloud computing could introduce learning-based applications, cultivating higher lifestyle standards. As manufacturers invest in the next generation of BAS, lower installation costs may get realized through pre-programmed application-specific installations.

Conclusion

BAS developers continue to explore a scalable, cost-competitive solution that supports standardized open communication protocols. Flexible BMS tailored for easy deployment and user-friendly configuration significantly contribute towards affordable operational costs. With rising energy costs, grid-hardened green buildings that also offer superior occupant safety and lifestyle convenience is a compelling proposition to future building solutions. Technology is at the foundation of building automation. Texas Instruments is leading the way to help buildings be in self-control, which may one day eliminate the many mundane tasks like making our beds. Until that day arrives, most of us will only have to wait and dream. ■



IWR6843ISK-ODS MMWAVE SENSOR EVALUATION MODULE

- Easy to use module for mmwave sensing
- 60GHz mmWave sensor
- Four receive (RX) three transmit (TX) antenna

LEARN MORE

CC1352P SIMPLELINK MULTI-BAND WIRELESS MCU

- Member of the SimpleLink™ MCU platform of cost-effective, ultra-low power RF devices
- Powerful 48MHz Arm® Cortex®-M4F Processor
- Multiprotocol Sub-1 and 2.4GHz wireless MCU

LEARN MORE

Designing the Elevators of the Future

By Kelvin Le, Texas Instruments

According to the United Nations Department of Economic and Social Affairs, two-thirds of the world's population will live in cities by 2050. With the fast-growing trend toward urbanization, smart people-sensing technologies in buildings, including artificial intelligence (AI), computer vision, and people counting, will help improve mobility, reduce inefficiency, and potentially increase building values. This article will explore how smart people-sensing technologies in elevator systems can help improve the passenger experience by reducing destination time (**Figure 1**).

One of the key goals when designing modern elevator systems is to reduce the average destination time for all passengers. In a 16-floor commercial office building, the average destination time is around 70s and the average wait time is about 25s. However, the time will fluctuate based on time of day. During lunch, the destination time in office buildings tends to be longer than morning, since the traffic is going both ways as people enter and leave a building.

Modern elevator systems strive to reduce passenger destination time and increase the efficiency of how people move throughout a building. Smart elevator group control algorithms can help predict and manage people flow during rush hours, such as in the morning and during lunch. A full elevator stopping at a floor to pick up more passengers is not an efficient operation—for those both inside and outside the elevator. In another example, sending an elevator to an empty floor (when someone requests an elevator but walks away) is also not efficient.

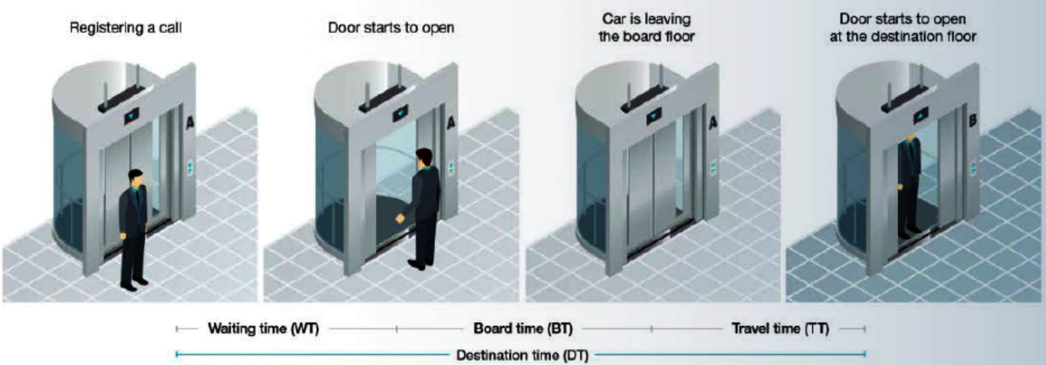


Figure 1: Three distinct time segments make up destination time: Wait time, board time, and travel time. (Source: Texas Instruments)

One way to address these challenges is by counting both those inside the elevator and those waiting outside the elevator in real-time, which can enable efficient and dynamic group control algorithms. The ability to distinguish people waiting outside versus people just passing by the elevator is also essential, as it will provide more accurate data for an elevator queue. Having smart people-detection capabilities—people counting and movement distinctions—enables the elevator group controller to prioritize elevator dispatch more efficiently. This improves the passenger experience and lowering energy usage and operating costs.

TI's industrial mmWave sensors for building automation enable the detection and tracking of people indoors up to 14m away. TI mmWave sensors may get employed for high-accuracy occupancy detection, where the position and velocity of people can trigger elevator systems upon a person entering an area of interest or moving in a particular direction. Also, the elevator door operations can get augmented with mmWave sensors (keeping door open or closing during boarding time). TI mmWave sensors use onboard processing to reduce false detection by ignoring signatures of static objects that are not of concern. These static objects may include items such as tables and boxes and even dynamic objects such as plants and fans. The sensors can operate in challenging environments such as dazzling sunlight, nighttime, and low-visibility cases like smoke, fog, and dust. With no camera or optical lenses, mmWave technology is also suitable for privacy-conscience applications. ■

"With the latest audio/video processors and wireless communications, doorbells are being transformed from century-old electric chimes to fully cloud-connected front-line security systems."

Enabling the Next Generation of Video Doorbells

By Srinivasan Iyer, Texas Instruments

These changes present a challenge for system integrators and embedded designers to fit power-intensive processing features like motion alerts, video analytics, two-way audio communications, noise cancellation, and cloud connectivity into a compact—and sometimes battery-powered—package that must also be reliable and easy to use. Home automation and home security technologies have transformed from a niche luxury to a suite of viable solutions accessible to most households. Simultaneously, the use of imaging systems for industrial automation, office security, and security systems has also evolved to include more advanced and connected surveillance functions.

A recent entrant into this market that benefits from the success of cloud-connected security cameras is the video doorbell. As homeowners and renters take their security into their hands or wish to monitor an increasing number of packages left at their front door, video doorbells have taken off and steadily become more feature-rich. This trend corresponds with the demand in the industrial sector for lower-cost and more elaborate video/audio security and monitoring systems.

Video-doorbell features now include advanced video processing using machine learning, cloud connectivity, and wireless communication, Power over Ethernet (PoE), battery backup power, advanced audio communications, and enhanced environmental sensing, along with motion detection. Integrating all of these features into a weatherproof electronics package that is small in physical size challenges design engineers. Design engineers must not only include these features but also leave room for upgraded performance and additional functionality for the next generation.

Technology Developments for Video Doorbells

Doorbell and entrance security systems with centralized video and audio capability have been around for decades. They have typically been used in large apartment buildings, offices, and high-end homes, and relied on closed-circuit television and human observation. With video/audio doorbells hitting the consumer market, a simple chime, one-way video, and two-way audio isn't enough to satisfy an Internet of Things-savvy home-automation enthusiast.

Industrial facilities are also requiring more secure, effective methods to monitor and identify potential threats or security breaches. This requirement is driving the inclusion of video-processing features in video doorbells that can distinguish humans, generate zoned alerts and produce automated responses based on visual evidence. Several video doorbells also function as 24/7 security cameras or offer similar capture, storage, and analysis features.

Although straightforward video-processing technology detects nonstatic objects, more complex and useful video processing requires advanced machine learning algorithms. These artificial intelligence systems are generally trained based on a variety of test cases, although some train continually using information from cloud-connected cameras. Thus, microcontrollers (MCUs) or more advanced microprocessors (MPUs) are often necessary to handle the edge processing and determine what information to communicate to the cloud.

Cloud Connectivity

There are two good arguments for designing a video doorbell with cloud capabilities. The first is their small form factor, which limits the processing power and storage. The second is the success of community watch organizations benefiting from connected doorbell applications. Consumers have become attracted to the ability to see their doorbell's video feed from anywhere and respond in real-time to what they see.

For personal/community security (or to confirm the receipt of packages), enabling cloud connectivity enables a wealth of user functions. Manufacturers can provide over-the-air-updates and acquire valuable usage statistics and information. However, the inclusion of cloud connectivity requires an internet access technology, be it hardline Ethernet or Wi-Fi®. Because most houses wired for chime doorbells only have some type of AC power and no Ethernet or other communication lines, Wi-Fi-enabled video doorbells are increasingly common.

Wireless Communications

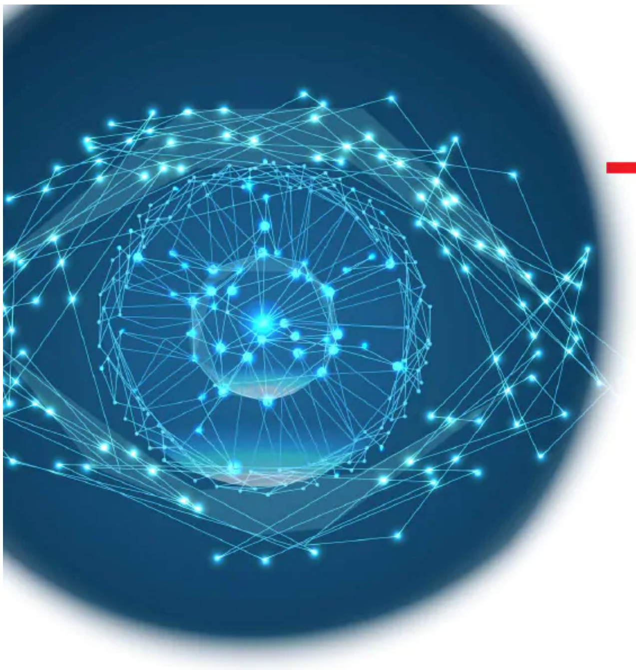
For simple audio applications, common wireless standards such as Bluetooth® and Zigbee have the specified bandwidth range to support audio-only doorbells. For video data transfer, however, Wi-Fi is the most accessible and popular wireless standard. In newer homes with builders aware of home-automation technologies, Ethernet connectivity may be possible—running a hard line to the front door is always an option. Given the amount of homes and apartments that get rented, it is more likely that renters will opt for nonintrusive installations with Wi-Fi-enabled doorbells. However, Wi-Fi doorbells also require a Wi-Fi router system, with good reception at each door where a video doorbell would get installed.

Power over Ethernet

For newer homes and those willing to do some minor renovations to enable the latest smart-home technology, power over ethernet (PoE) can allow a single-wire installation for a relatively high-performance video doorbell. Many of the newest video doorbells exceed the power-output capability of typical (or worn) doorbell transformers and may require upgrades, including running new AC wiring. With PoE, a video doorbell could benefit from reliable and secure hardline communications as well as up to 100W of power, according to the Institute of Electrical and Electronics Engineers (IEEE) 802.3bt standard defined in September 2018. Leveraging PoE enables the delivery of dynamic power without the concerns of current limitation on AC/DC power solutions.

Battery Power and Battery Backup

Because many homes and apartments are not wired for a doorbell at all, adding external wiring for power and internet connectivity may be impossible for many potential video doorbell customers. Also, most video doorbell owners would prefer that power outages, brownouts, or intentional sabotage do not disable the newest extension of their home security system. Thus, video doorbells that operate on battery power (or those that at least include a substantial battery backup) also have their place in the market. Batteries find employment in both active power systems and complete Wi-Fi systems, where intelligent charging and seamless power transition/supplemental power are critical requirements in delivering backup power while retaining battery-life expectations.



Advanced Audio Technology

Aside from the video features, audio functionality is another major technology in video doorbells. There are even competitive doorbell technologies that offer audio features without video. Two-way audio, audio-triggered events, and audio-direction sensing are standard in most video doorbells. Although two-way audio requires at least a speaker and a microphone, audio-triggered events and audio-direction sensing require additional audio-processing technologies and often additional microphones. Audio event triggers and two-way audio are generally implemented using algorithms inside a digital signal processor or codec. Encoded audio data regularly gets communicated to an app or cloud storage.

Motion Detection and Environmental Monitoring

One of the main functions of a video doorbell is the ability to detect motion. Although many video doorbells rely purely on motion tracking through image processing, a variety of other methods can aid in motion detection and help eliminate false positives. These technologies include a relatively low-cost and straightforward process called a passive infrared (PIR) detector. PIR detectors are standard in motion-detector lights used for security illumination; however, this method gets limited to warm objects such as people and large animals. To avoid false alarms, PIR sensors get commonly paired with additional sensors.

In addition to visual and auditory sensors, a variety of other environmental sensors and functions can help improve video doorbell performance based on external conditions. For example, ambient light sensors help image-processing algorithms properly adjust the video exposure based on the outside light. Other standard sensors include external and internal temperature sensors, battery temperature sensors to monitor charging and discharging thermal shifts, and other sensors to indicate tampering or theft. Anti-theft or anti-tampering sensors include vibration, shock and proximity sensors, or simple switches attached to critical parts of the housing. The power-management circuitry may also feature current and voltage sensing to determine power quality and whether to engage the backup battery. Additionally, a variety of internal fault sensors monitor the proper operation of critical circuit components for troubleshooting and servicing.

Key Video Doorbell Technology Challenges

As is typical with electronic designs, each additional feature generally adds its share of design challenges and extra circuitry. This is undoubtedly the case with video doorbells, which are also commonly power-, space-, processing- and cost-constrained, further challenging design engineers to innovate with the right combination of hardware, software, and cloud resources.

Doorbells are primary powered up with 8V–24V transformers rated from 5VA–30VA. With the availability of PoE, higher power demands of video doorbell can get met as the latest IEEE standard allows up to 71W of power delivery. Having a front end power stage capable of working on a traditional transformer power scheme as well as PoE schemes calls for innovative power architecture to work on wide input voltage range and maintains the PSE controller link in light load conditions.

The size, power budget, and thermal-management capabilities of a video doorbell place significant constraints on the processing power that may get included. Given the feature complexity, including audio and video processing, the MCU or MPU processing power needs to be significant on demand but also consume minimal power in the off state. A full processing load may cause the MCU to generate considerable heat, but the device still needs to operate in wide temperature extremes. As a consequence, designers must also consider a balance of processing power, thermal load, environment temperature, and thermal management.

Another method of enhancing video doorbell abilities without increasing the processing power is to offload the processing to cloud services and stream the audio and video data. However, this method requires a highly reliable communication infrastructure capable of one-way continuous transmission.

It is still relatively uncommon for video doorbells to support Ethernet connectivity; therefore, Wi-Fi is the standby connectivity solution. A reliable wireless connection that can support the necessary bandwidth for high-quality video and audio streaming is not easily accomplished. This is especially the case when considering power constraints and doorbell locations. Outdoor installation exposes doorbells to harsh environments and poses practical issues for high-bit-rate streaming.

The compact form factor of wireless doorbells also limits the space and gain of the antenna design. Since consumers have little choice over where to position their doorbell—and most Wi-Fi router installers likely don't consider the doorway a prime location for Wi-Fi—a video doorbell designer must carefully select a Wi-Fi-enabled microcontroller. The microcontroller must have good receiver sensitivity and low-phase noise to operate in areas with poor reception. Although a typical video doorbell should have at least 1Mbps of bandwidth, a high-end video doorbell or a video doorbell that suffers from a poor connection may require as much as 3Mbps.

A sophisticated printed circuit board antenna design or in-package antennas can reduce bandwidth performance degradation from building materials and nonideal placements. Moreover, highly efficient Wi-Fi chips or MCUs with embedded Wi-Fi front ends can further enhance reception and transmission performance to meet power budget limitations.

Including a battery backup in a product is more complicated than merely including a low-voltage detection switchover to the battery system. There is also battery charging, discharging, and maintenance to be concerned about. Given the form-factor limitations, it is likely that many video doorbell manufacturers will choose a lithium-ion (Li-ion) or nickel-metal hydride (Ni-MH) battery technology. Li-ion batteries are some of the most energy-dense of the readily available battery technologies. This type of battery is also very susceptible to performance degradation from high- and low-temperature operation, while Ni-MH suffers from excessive self-discharge issues. Li-ion battery chemistries can also overheat during charging and discharging without additional charge/discharge controllers to provide temperature sensing. Because battery thermal management depends on external environmental conditions—mainly temperature and humidity—it may be advisable to include gauging functions that use complex algorithms or even machine learning to determine the best charging/discharging conditions for a given battery configuration.

Although image-processing algorithms can effectively track and even identify stationary and moving objects, the circuits and algorithms capable of doing this in real-time generally require high-power processing technology. Since this isn't always ideal, many video doorbell manufacturers opt to use multiple motion-detection technologies in synergy with image-processing systems. PIR detection and, more recently, millimeter-wave motion detection are viable technologies that could work in conjunction with a video-processing motion detector. These technologies may even save substantial power when operating in passive mode. Image-processing methods for motion detection also tend to fail frequently at long distances, where the resolution isn't adequate to yield a high level of confidence. Both millimeter-wave and PIR motion detectors have a range of several meters in passive mode. Furthermore, millimeter-wave sensors, such as those used in single-chip radar systems for automobiles, can provide accurate and high-speed motion and object detection.

Video doorbells often get reviewed on their ability to pick up clear audio from intended parties. It is imperative that a video doorbell can determine the direction of a speaker or event concerning the door. One of the reasons why this is an important feature is because background noise and outside disturbances do occur on most metropolitan (or even rural) doorsteps. Even under ideal conditions, a video doorbell can't account for all possible scenarios. Therefore, the use of direction-of-arrival audio-processing features can reduce background audio and focus in on the intended target.

There are a variety of methods to achieve such capabilities, including directional microphone systems, beamforming with antenna arrays, and microphone arrays configured to far-field reception instead of near-field reception. Each method comes with its challenges, usually entailing the need for additional microphones and additional circuitry to process real-time audio. The exact circuitry that combines multiple signals from various microphones and determines the correct processing dynamics is not trivial. This is especially true when considering noisy and diverse metropolitan environments, with substantial amounts of background noise directly conducted through the air to both the microphones as well as the doorbell's housing.

Finally, problems with false chimes and security vulnerabilities are a significant challenge for every video doorbell manufacturer. Many reviewers of video doorbells complain that large trucks, objects that experience high glare, and even vehicles or local advertisements (typically those with human faces on them) can trigger false alarms and chimes. These false positives are generally seen as a nuisance.

Reducing the number of false chimes requires more sophisticated image-processing artificial intelligence/machine learning, efficient and dynamic power scheme, and possibly operational modes that account for the environment where the video doorbell gets installed. Additionally, sensor fusion with a variety of motion-detection algorithms, as well as audio-processing systems, could serve as a backup to investigate, identify, and dismiss potential false chimes. With an intelligent application, users may even be able to participate in the detection algorithms by confirming whether a chime was a false positive or not, enabling a video doorbell to calibrate more precisely to its environment.

Conclusion

As competition and consumer familiarity with video doorbells increases, so does the need for video doorbell manufacturers to diversify their offerings with enhanced feature sets and innovative designs. The main challenge lies in handling the age-old problem of enabling higher performance in smaller and lower-cost packages that provide convenience and seamless integration with smart-home configurations. Many video doorbell manufacturers are turning to highly integrated MCU chips with Wi-Fi capabilities and advanced sensor technologies to better augment the performance of video- and audio-processing artificial intelligence/machine learning algorithms. ■

Extending Battery Life in Smart Locks

By Chris Glaser, Texas Instruments

Power management is a crucial design challenge in every Internet of Things (IoT) and connected home product. If the consumer experiences product downtime due to dead batteries or gets tired of changing the batteries too frequently, they will likely choose not to use the product. This is especially true for smart locks. When a lock malfunctions, the result is frustration from being locked out of the office or hotel room. In addition to the relatively high peak current demands of the radio, common in all IoT applications, smart locks have an additional high peak current requirement from the motor, which turns the lock itself. Also, smart locks sit idle for the vast majority of every day—the time when they are actively locking or unlocking the door is minimal. This combination of high peak current demands and very lengthy, low-power system standby time demands new power architectures to extend the battery life.

"New smart lock power architectures greatly increase battery life by reducing system standby power consumption."

System overview

While smart lock systems may contain many integrated circuits (ICs) such as light-emitting diode (LED) drivers, Wi-Fi® communications, and other items, this article focuses specifically on the following three ICs.

1) Microcontroller with wireless connectivity, such as Bluetooth® low energy

2) Motor driver

3) Power management

The term "events" refers to the door locking or unlocking when the motor is active. For example, locking the front door and then unlocking the front door counts as two separate events. Twenty-four events per day is commonly employed for comparing the performance of different smart locks.

Wireless microcontroller

In a smart lock product, the wireless microcontroller (MCU) device communicates with the phone to lock and unlock the door wirelessly. To do this without any noticeable lag, the wireless microcontroller needs to be powered on to send an advertising event signal periodically, and then be put back into its standby state. Current consumption is much lower in standby—usually around the single-digit micro-amp (μA) range. Such a low current enables extended battery life. Advertising events (not to be confused with the locking/unlocking events) occur when the wireless microcontroller periodically wakes up to briefly transmit identifying information and listen for incoming connection requests from peer devices (e.g., a smartphone). The period of advertising events is programmable on most Bluetooth low energy devices from 20ms to 10.24s.

The longer the period, the longer it takes for a connection, but the smaller the power consumption. A period of 500ms between advertising events is an appropriate balance between power consumption and connection speed. **Figure 1** shows the current consumption waveform of a typical wireless microcontroller with Bluetooth low energy communication. Default values for the CC2640R2F current consumptions are shown in **Figure 1**. The pie graphs and plots in **Figure 6** and **Figure 7** use the worst-case scenario of 9.1mA of active current and 2.5μA of standby current. These values are used for maximum output power. Since the advertising event period is programmable, the two most important values to look for when choosing a Bluetooth low energy radio, in terms of power consumption, are active (during an advertising event) and standby currents. The supply voltage range of the SimpleLink™ Bluetooth low energy CC2640R2F wireless MCU is 1.8V to 3.8V. In this article, 2.5V will be used to allow easy comparison between the different configurations.

Motor

All smart lock products need a motor and motor driver to turn the lock in either direction (lock and unlock) wirelessly and without a physical key. The current profile of the motor is different for each type of door lock because the amount of torque needed to turn the lock differs between different brands of door locks. On many locks, the current through the motor ramps up and peaks at around one amp. There are several sources of power dissipation in a motor driver, but the most significant source is the on-resistance of its MOSFETs. When choosing a motor driver, the highest efficiency get achieved with a very low on-resistance. The motor driver, such as a DRV8833, must work with the smart lock's power source and the specific motor used. Considering both of these, the motor driver voltage is typically around 5V.

Power Management

Power management is required to convert the varying battery voltage to the voltages needed for each of the loads: Wireless microcontroller, motor driver, and any other sub-systems. Power management adds cost, size, and inefficiency to the system. Thus, it is essential to design the entire system with the power management in mind—the power management must work together with each sub-system.

The power management's efficiency is critical to the performance of the overall system, especially in an IoT application such as a smart lock. This efficiency is vital at the full system load with motor turning and wireless microcontroller connecting, but critical when the system is in standby-mode—drawing microamps (μA) of current. Being efficient at both light and heavy loads is challenging and requires specially-designed ICs. The power management must ultimately run off of the user-installed batteries. The choice of battery type, number and configuration goes hand-in-hand with the system's power architecture and power management selection. AA-size alkaline batteries find extensive utilization in smart locks due to their high

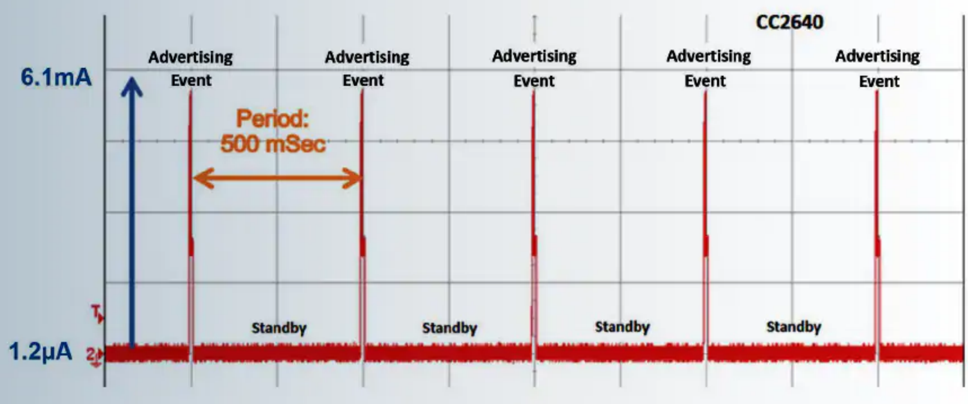


Figure 1: Current consumption versus time during a Bluetooth low energy advertising event.

availability to consumers and low cost. The average per-cell voltage of an AA cell is around 1.25V, though their voltage varies from under 1V when fully discharged to 1.6V when brand new. With four (4) AA cells, over four years of battery life is achieved.

Whereas many existing smart locks focus on achieving lowest-cost power management with low drop-out (LDO) linear regulators—at the expense of efficiency—newer, cost-effective power management more than doubles the battery life with minimal added cost. Switching DC/DC converters, both boost (sometimes called a step-up) and buck (sometimes called a step-down) converters, offer higher efficiency and a corresponding longer battery life compared to LDO implementations.

Figure 6: Three pie graphs of the power consumption of all three system blocks in a real smart lock for one day of operation. The percentages show how much of the total system power budget gets employed for each of the three sub-systems. The bar charts show the total power consumption in each power architecture. A 500ms advertising period and 24 lock/unlock events per day gets employed in the calculations. For visual representation, the overall size of each pie chart is proportional to the total power used for each of the three power management architectures—the bigger the pie chart, the higher amount of power consumed. The height of each pie chart also shows the total power consumption.

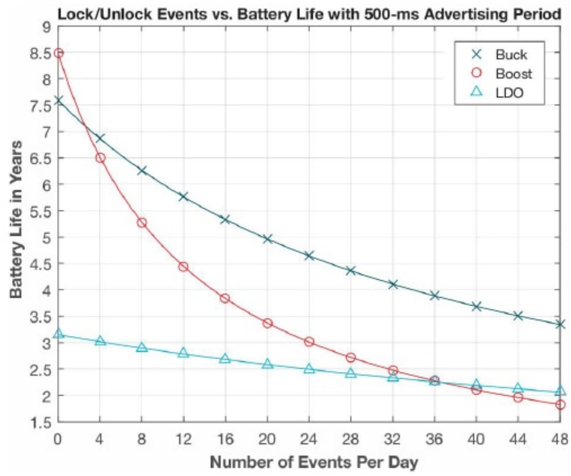


Figure 7: Battery life versus power architecture and number of events per day.

Figure 7 shows a comparison of all three power architectures with the number of lock/unlock events on the x-axis and the number of years of battery life on the y-axis. For many applications, which have less than 36 events per day, both the buck and boost architectures offer an improvement in battery life compared to the LDO architecture. For higher lock/ unlock event systems, the buck architecture is still best. However, the boost architecture becomes worse than the LDO architecture due to the higher amount of motor power required for more events.

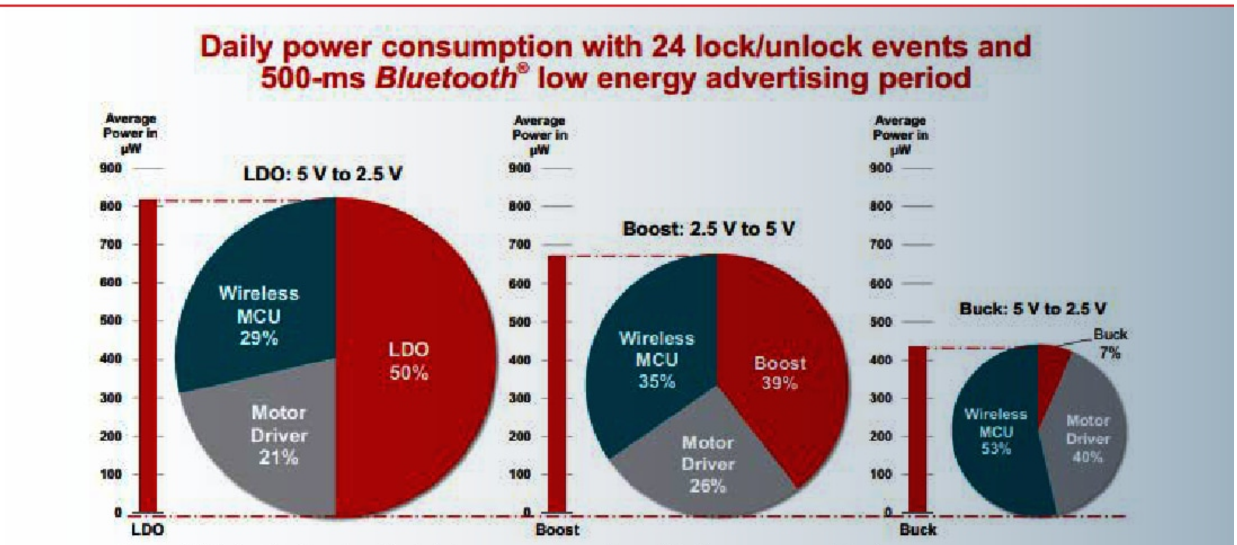


Figure 6: Total and sub-system-level daily power consumption of the three power architectures.

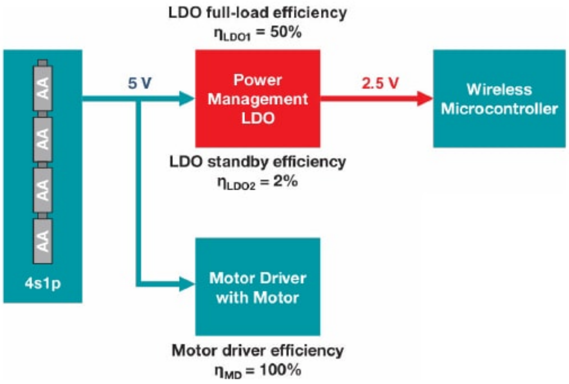


Figure 2: Smart lock block diagram using an LDO and four AA cells.

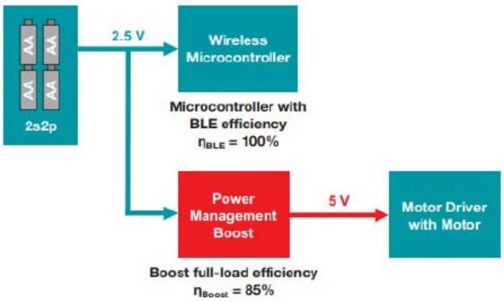


Figure 3: Smart lock block diagram using a boost converter and four AA cells connected as 2s2p.

Linear Regulator

The four AA batteries are connected as 4s1p (four series cells and one parallel cell) to create a 5V supply voltage to power the motor. Now, only a simple motor driver is needed to turn the motor on or off without any added power management. Because of this, the motor sub-system operates at nearly 100 percent efficiency.

LDOs step down the higher battery voltage to lower voltages. An LDO is used to convert the 5V battery to the 2.5V required by the wireless microcontroller. Any LDO converting 5V to 2.5V is 50 percent efficient at best, with much lower efficiency obtained in standby-mode due to the LDO's quiescent current (sometimes called ground current). For example, the TPS76625 is suitable to convert four AA batteries to 2.5V. This device achieves 50 percent efficiency at higher loads, but only two percent efficiency at the 1.2µA standby load due to its 35µA quiescent current. The meager efficiency results in relatively high power consumption when the smart lock is in standby—this reduces battery life. **Figure 2** shows a typical block diagram of an LDO-based system.

Boost Converter

To overcome the LDO's low efficiency in standby mode, the battery configuration is rearranged, and a boost converter may get employed instead. In this power architecture, the wireless MCU connects directly to the battery pack, which gets arranged as a 2s2p (two series and two parallel cells). Since four cells are still used, the cost and energy are the same as the previous case. But since there are only two cells in series, the total battery pack voltage is just 2.5V—a perfect match for the wireless MCU. Now, this connection is 100 percent efficient.

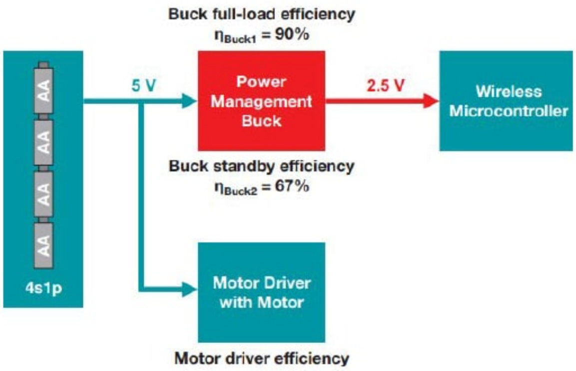


Figure 4: Smart lock block diagram using a buck converter and four AA cells connected in series.

However, the motor still requires 5V to operate. From the 2.5V battery, a boost converter must get employed. A typical boost converter, such as the TPS61030, has around 85 percent efficiency when boosting to drive a motor. Due to the efficiency and boost ratio (where the output voltage is higher than the input voltage), the boost converter draws very high currents from the battery which increases the losses. **Figure 3** shows a typical block diagram of a boost-based system.

Buck Converter

Taking the same power architecture as the LDO system, a buck converter is used in place of the LDO to increase the efficiency dramatically. At the wireless microcontroller's full

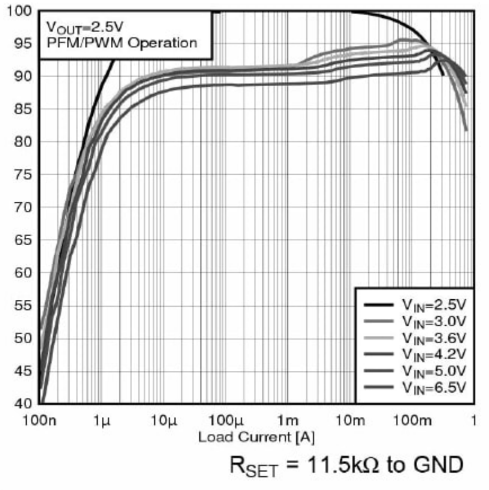


Figure 5: An ultra-low power buck converter's efficiency remains high, even at very light loads.

load, the buck converter, such as a TPS62840, is 90 percent efficient. The motor sub-system remains at nearly 100 percent efficiency because it is connected directly to the battery pack. **Figure 4** shows a typical block diagram of a buck-based system.

A standard buck converter has a relatively sizeable quiescent current (IQ). The high IQ dramatically decreases efficiency in standby-mode as it did with the LDO. However, the ultra-low-power buck converter used in this example has ultra-low IQ specifically designed for IoT applications, which have higher peak currents and significant system standby times. **Figure 5** shows that the ultra-low IQ enables over 80 percent efficiency at the typical standby mode load currents with a 2.5V output voltage.

Power Management Architecture Comparison

The efficiency of the power architecture is critical for extending the smart lock's battery life. Power management is necessary to convert the battery voltage to what is required by each sub-system, but it consumes some of the battery's energy to function.

Conclusion

New power architectures in connected devices, such as smart locks, enable much higher battery life compared to the current LDO-based implementations. A switching power converter, either a boost or buck, increases battery life for smart locks with less than 36 lock/unlock events per day. An ultra-low-power buck converter more than doubles the battery life for lower event systems, while nearly doubling the battery life for higher event systems. The ultra-low IQ of such a buck converter is critical to the battery life extension by vastly increasing the efficiency during the lengthy standby-modes of such systems. Designers of connected and IoT products should take another look at their power management architectures to make sure their products achieve optimal battery life. ■

Smart Connected Lighting and the IoT

By Paul Golata, Texas Instruments

Sunlight Seasons

Seasons come and seasons go. I am subject to the rhythms of nature and the change of its seasons. Nature's seasonal transitions encompass the changing cycles of available sunlight for me.

Writing this article, located from my position in the Northern Hemisphere, I am experiencing the time of the December solstice. The winter solstice is that day of the year when I will receive the least amount of sunlight—as measured from sunrise to sunset (**Figure 1**).

Shortly, spring will appear. The days will lengthen and the amount of sunlight will increase. I enjoy this lengthening of days with its increasing amount of sunlight. It always seems to make my moods feel better. I can take advantage and make the most of the remaining daylight after work, often riding my mountain bike through the woods, over the roots, and down and up the ravines. This changing season's length of sunshine goes on automatically, without any need for my input or control.

Man is smart, so he has created devices that provide himself with light. In cities, towns, and villages throughout the world, man harnesses his own created-illumination devices to gleam light into the recesses of the darkness. Civilized society, a connected social order advancing cultural creation, employs these lighting devices in order to chase away the darkness and pave the way for a brighter future.

At one time, this source of light was through items like wax candles. What a mess! It must have taken great efforts and pains to illuminate a large location and keep it well lit.

However, the technological reality of the Internet of Things (IoT) now empowers smart connected lighting within a coordinated system. Hardwired and wireless systems allow secured data to connect lighting systems through a coordinated and intelligent approach. This article articulates how smart connected lighting is enabling a bright future.

Smart Connected Lighting

A season of change is underway. The IoT is dawning today as a revolution in technology. Smart sensor technology and radio-frequency (RF) wireless connectivity have combined to produce new methods to sense and collect data and get it onto the internet. IoT is enabling building automation utilized for industrial and personal (home) use. Automation within buildings and cities is taking advantage of human intelligence. Specifically, it is aiming to program electronic systems in a coordinated and integrated fashion to mimic or improve upon this human intelligence, thus providing an automated system with a level of smartness. In this case, smartness means the ability to meet and perform to an acceptable level of a desired aim or goal. The goal of these efforts is to produce more intelligent and robust systems, which will improve people's living conditions while lowering costs and decreasing negative environmental impacts.

The past several years have seen a rapid movement from traditional lighting sources to light-emitting diodes (LEDs). The success of LED lighting adoption is a natural pathway for software-controlled, smart, digital, connected lighting systems. Where previously simple up/down or push-button on/off switches were employed, today IoT coupled with electronically controlled lighting products are enabling smart, connected lighting applications.

Connected lighting systems consist of three key ingredients:

- A light source such as a light bulb or LED
- A light fixture and electromechanical assembly to connect and secure the light source to its location, and
- A light switch or controller

Figure 1: The sun sets during the winter solstice in British Columbia, Canada. (Source: Mouser)

Smart connected lighting, deployed in smart buildings, takes advantage of multiple electronic systems and platforms, including motion sensors, integrating them with a variety of lighting control methods to provide solutions to suit virtually any lighting-control setting. Connected by means of the IoT and employing open and configurable infrastructures, data can be collected and utilized for intelligent decision-making and effective operations. Software's great flexibility and the simplicity of digital design and control provide advantages for smart lighting platforms. Leading electronic component vendors are presently developing LEDs, LED drivers, sensors, power electronics, and various electronic control devices for smart lighting products. It is a discernible trend that these manufacturers are working to ensure that their products successfully integrate with or within designs in the building automation industry.

Automated lighting systems set up in this manner are called smart lighting. In the future, businesses and homeowners will increasingly take advantage of the leverage provided by connected lighting and the IoT. Smart lighting allows for autonomous and programmed control of illumination levels and colors and simultaneously identifies when traffic or building occupancy activities warrant adjustments, providing for a more optimized experience for users and owners. Regardless of whether it involves illumination lighting in offices, in homes, or in street lights and lamps for traffic or pedestrians, automated smart lighting is found across the modern urban landscape. Smart lighting is fast becoming the mainstay of intelligent automated buildings in smart cities (**Figure 2**).

Wired and Wireless

Smart and intelligent control of lighting systems requires solid and reliable connections. There are two primary networking methodologies that bring together smart connected lighting and IoT: Wired and wireless. In addition, these two primary networking methodologies may be employed in various cooperating combinations, employing various communication methods and protocols such as Bluetooth® mesh networking, and be limited only by the requirements of the application and the engineer's creativity.

Figure 2: Modern intelligence buildings in Shanghai, China offer innovation using illumination. (Source: Mouser)

A wired network relies on direct physical electrical connections between points in the network. A wireless network requires no physical connection between devices, providing freedom from hard wiring. Wireless networks make it possible for devices within the network to roam untethered. There are advantages and disadvantages to both approaches. A smart design engineer will consider what is best for an entire application and may design a solution that takes advantage of both networking methodologies' respective strengths while mitigating against their respective deficiencies.

Smart connected lighting within the IoT requires an engineer who understands acceptable system design, speed, bandwidth, and low-latency connection specifications. Hardwired systems offer top performance in these specific specification parameters yet require switches to be hardwired to lighting fixtures, thereby decreasing flexibility. The incorporation of wireless designs may sacrifice some of these specifications but provide configuration control and management options that cannot be accomplished within the limitations of hardwired designs. However, ongoing and dramatic improvements in RF wireless technology performance are providing wireless design options previously not conceivable or available.

Smart lighting controls and IoT often employ wireless mesh topologies, where there are redundant interconnections between network nodes (**Figure 3**). These so-called "many-to-many" topologies offer exciting potential for smart lighting control: Primarily because their redundant interconnections protect against single point node failures while simultaneously offering low latency, high speeds, and excellent efficiency. Zigbee and Bluetooth mesh are two popular protocols.

Figure 3: Mesh network connections produce exciting potential for smart lighting control. (Source: Mouser)

Zigbee and Bluetooth Mesh

Low-powered and standards-based wireless sensor network (WSN) products may be incorporated to meet the demands of smart connected lighting applications. Mesh enabling systems are deployed worldwide, securely connecting a variety of smart devices to applications, delivering smarter, greener, more efficient solutions.

Zigbee, like Bluetooth, is a specification for communications in wireless personal area networks (WPANs). Designed to be low cost, low power, and low duty cycle, Zigbee technology is ideal for WSNs and other low-power networks that span potentially large distances. Zigbee builds upon the IEEE 802.15.4 standard but adds the mesh networking capability with multi-hop functionality and a routing protocol. Star as well as peer-to-peer (e.g., mesh and cluster tree) networks are supported, making Zigbee dynamic, scalable, and decentralized. Zigbee technology is not meant to compete with technologies such as Wi-Fi (IEEE 802.11) or Bluetooth (IEEE 802.15.1). Rather, Zigbee is designed for applications where the data transfer rate is much less important than power efficiency, network size, and ad hoc routing capacity.

Bluetooth mesh networking (introduced in July 2017) is a protocol based upon Bluetooth Low Energy (BLE) that finds application in smart connected lighting and IoT. It employs a Bluetooth radio that can operate over a physical distance of approximately 100 to 1000m. Being new to the scene, it is still seeking to demonstrate successful large-scale

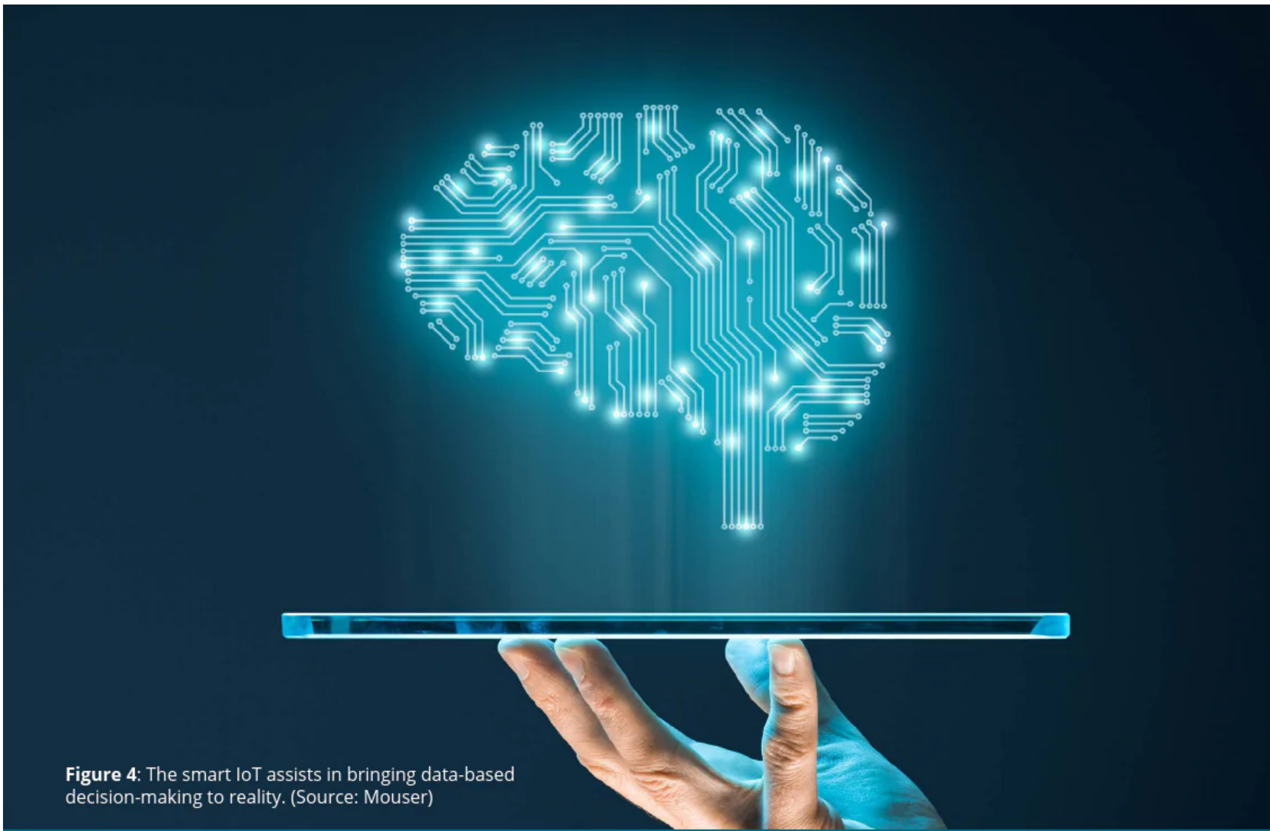


Figure 4: The smart IoT assists in bringing data-based decision-making to reality. (Source: Mouser)

deployments, efficiency, and effectiveness. A large assortment of talented persons and companies are working steadily to make improvements.

Data

Socrates (470–399 BC) stated that virtue is knowledge. Francis Bacon (1561–1626) declared that with knowledge comes power. In the IoT applications of tomorrow, the collection, storage, and analysis of data will drive knowledge. The IoT will harness data-driven insights, which will assist business and personal decision-making. This trend will provide a host of new ways to perform and utilize smart connected lighting, including protecting and monitoring against power failures and blackouts as well as assisting with scheduling regular upkeep and maintaining the highest level of overall operational effectiveness. The demand for low-latency, real-time decision-making and response, which is imperceptible to humans (<0.05s), will incite the incorporation of more sensors to collect data. This data will undergo analysis and processing in the "smart" edge, providing new and greater insights and increasing the opportunity for new markets and value creation. Smart connected lighting works to bring data-based decision-making to reality (**Figure 4**).

Security

Data transmissions must remain under safeguards against adverse contingencies and situations. Reliable and secure connections are a must. Wired systems can be cut or tapped, and wireless systems might experience interference, droppage, or access by suspect or nefarious methods. Smart connected lighting systems and the IoT use a multilayered approach for protection, applying safeguards at several different points throughout the system.

Key steps in this multilayered approach might include creating proper credentials and access authorization passwords in an appropriately compliant and protected operating system (OS). Employment of appropriate protocols will empower the connection of devices while providing strong and robust performance and security under a wide variety of operating conditions. Every connected device should be monitored and be compliant with the appropriate firmware and software revisions to take advantage of up-to-the-moment protections and safeguards. Collected IoT data should be ingested and validated prior to consuming and processing it at lower-level stages and prior to higher-level processing to prevent ingress errors at the cloud or at higher-level data-processing sources (**Figure 5**).

Figure 5: Data protection is essential within, to, and from a smart connected lighting system. (Source: Mouser)

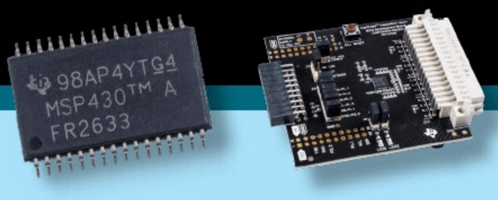
Future

The seasons change and so does technology. The IoT opens the door for smart lighting to be connected in a coordinated system. Hardwired and wireless systems allow secured data to connect lighting systems through a coordinated and intelligent approach. This smart connected lighting and the IoT are the technologies of our next and brighter season. Just think how far we have advanced since the days of fire, candlelight, and Edison's light bulb! ■

TLV320AIC3262 STEREO AUDIO CODEC

- Stereo Audio DAC with 101dB SNR
- Eliminates large output DC-Blocking capacitors
- Eight single-ended or 4 fully-differential analog inputs

LEARN MORE



MSP430FR263X / MSP430FR253X ULTRA-LOW-POWER MCUS

- Embedded microcontroller
- Optimized ultra-low-power modes
- Free Professional Development Environments

LEARN MORE

No, It's Not a Ghost: AI in Lighting

By Paul Golata for Texas Instruments

In childhood, there's always that one building that everyone thinks is haunted—where lights suddenly switch on when someone enters the room, objects develop a mind of their own, and machines magically come to life. Luckily, it's not a ghost, so no need to call Ghostbusters.

Rather, there's something more logical at play controlling things from a distance. As engineers, we are aware of the advancement of artificial intelligence (AI). AI is a technique that allows computers and machines to emulate human behavior. A subset of AI is machine learning (ML) whereby AI techniques are combined with statistical processing techniques to enable computers and machines to "learn" by making adjustments that improve them on the path toward their goal.

AI is impacting almost every field and application, including the city and spaces we occupy. Smart cities, where intelligent sensing and processing networks along with AI and ML, will endeavor to transform our surroundings and home, work, and play environments. Impacting municipal-wide lighting infrastructure, buildings, utilities, transportation, environment, and communications, smart cities are poised to change how we interact with the world around us.

Some estimates state that lighting accounts for one-sixth (1/6) to one-fifth (1/5) of total present energy consumption. The arrival of AI may enable the commissioning of building lighting control and automation to save money, reduce energy consumption and waste, and improve the level of service quality and customer satisfaction. AI will act as an unseen intelligence providing decision-making capabilities that will help provision future smart buildings. Read on and see how generally invisible AI will help control our visible lighting environments (**Figure 1**).

Introduction to Smart Lighting

Smart lighting systems are lighting systems that have communication and control systems integrated into them. The incorporation of these systems allows for potentially greater automation and flexibility. Wireless communication aids in covering vast distances. Control flexibility increases because the overall lighting response can get tuned at three primary points:

- Overall (macro-level)
- Edge (local level)
- Particular (device level)

Smartphones, computer systems, or wall fixtures can operate as control and switching stations. Color or white levels may receive adjustment through the manipulation of red, green, blue, white combinations to provide the specific wavelengths and correlated color temperature (CCT) desired. Output light levels, measured in lumens, can be adjusted to control the amount of optical power delivered by location. Lamps, recessed lights, architectural (indoor/outdoor), signage, and landscape lighting can all be coordinated together within one single system.

Figure 1: AI will impact the future of smart lighting control and automation. (Source: Mouser)

Figure 2: The future of smart lighting employs AI to emulate human behavior and learn how to operate autonomously. (Source: Mouser)

AI: Learning and Lighting

I had to go to school for many years to learn all sorts of things. Some things, like my ABCs, I nailed down early, while other things like Quantum Physics and handling Laplace transforms as easily as mathematical addition took me many years to equate.

AI is a significant technology disruptor. One of the characteristics that AI brings to smart lighting is learning. AI allows smart lighting systems to improve their performance in a manner that is analogous to feedback in an electronic circuit. This learning and refinement function is called ML.

ML generally employs a large amount of data. As data is analyzed, the computer is allowed to make decisions. These decisions are called inferences. Inferences are conclusions reached based on evidence and logical reasoning. This type of processing is well-suited for a computer.

The computer system learns by one of three methods:

- Supervised learning
- Unsupervised learning
- Reinforcement learning

Supervised learning employs by providing and comparing the desired best correct answer response (output). Its complement, unsupervised learning, by contrast, does not contain any information regarding what is the desired best correct answer response (output). Reinforcement learning provides appropriate positive or negative feedback based upon what the best correct answer response (output) should be. Because computers have high computational capabilities, they can often make dramatic improvements in their reinforcement learning rather quickly in comparison to humans without the aid of computers (**Figure 2**).

Adoption

A wide variety of industries are incorporating AI. Banking, retail, automotive, and medical are all industries that have taken a significant foray employing AI within their respective fields. It is evident that although AI will be pervasive, it will be adopted across different industries at different paces. Knowledge and lessons learned in these fields will flow over into the industrial application space over time.

The breadth and scope of the industrial control sector, including smart lighting, is enormous. Organizations with particular and specific knowledge of their smart lighting control and automation parameters will be able to adopt faster than those who have farmed this duty to outside firms. AI and ML implementation is easier for organizations who have initial conceptions of how they should address learning algorithms to tackle the specifics of their organizational challenges and goals. An understanding of the existing system's limitations and interrelations will provide specific areas in which to focus and apply AI in building lighting control and automation solutions. AI can be tailored to address application-specific areas that the organization

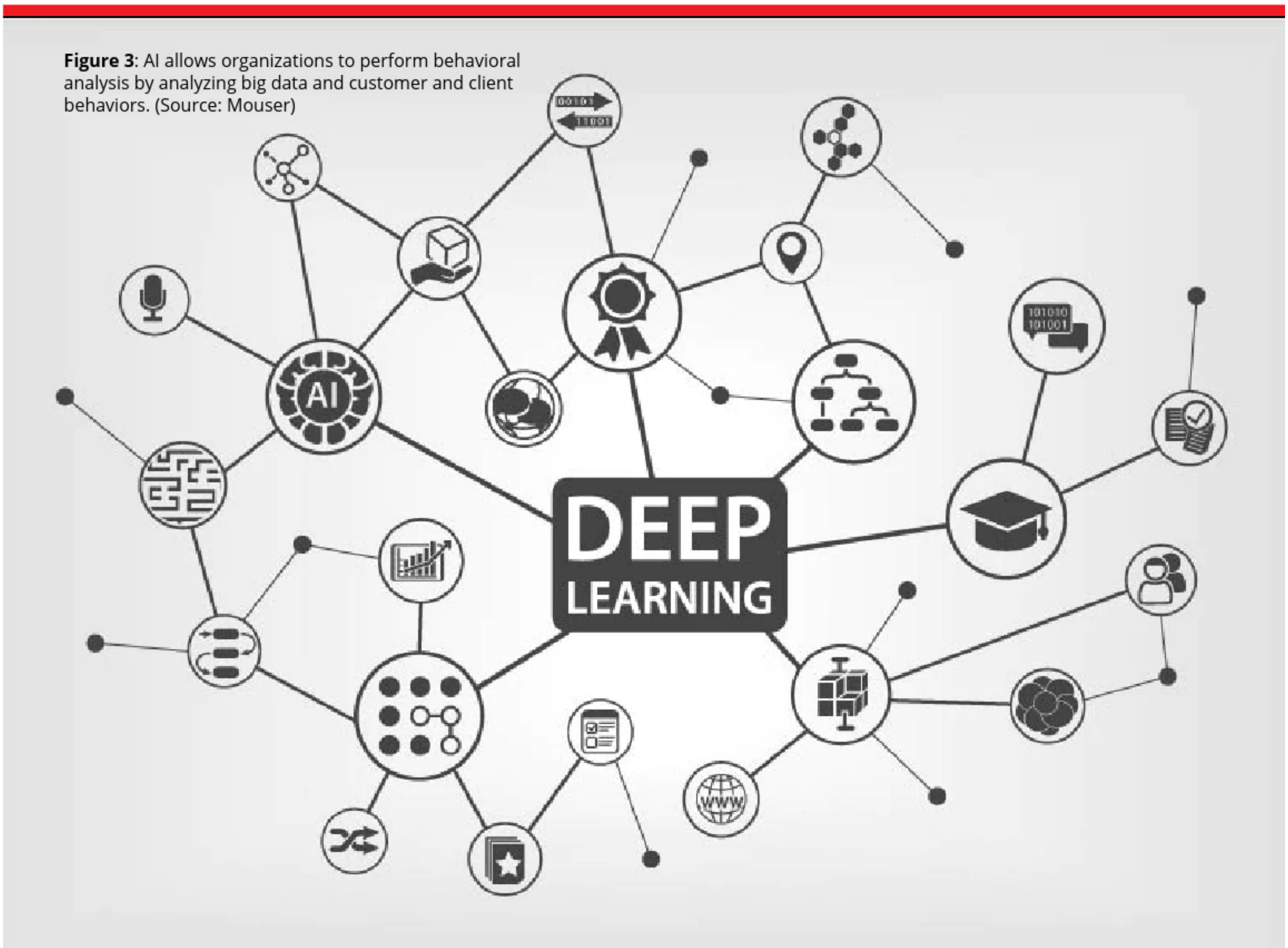


Figure 3: AI allows organizations to perform behavioral analysis by analyzing big data and customer and client behaviors. (Source: Mouser)

desires to control and automate. AI is a tool that has many uses. Like a handyman with a well-equipped tool belt, it has at its disposal a wide variety of contexts and applications that it can apply.

Due to the diversity of activities within the industrial space, common higher-level functions, with the greatest level of return on investment (ROI), will yield the primary market entry points. Areas where human safety and overall security concerns and risks represent large financial exposures will likely be the first industrial areas employing large amounts of AI. Secondarily, industrial AI applications such as smart lighting, where relatively similar level high-level systems can be quickly adapted and modified, represent areas for adoption. Without a doubt, organizations should be looking at and strategizing now as to how AI offers the possibility of increasing efficiency and efficacy.

Behavioral Analysis

Despite the reality that people are difficult to explain, there is little doubt that people are often doing things in a characteristically predictable fashion, even if each particular action has variations or is subject also to a different response and subsequent action. Psychologists and sociologist often get paid to learn how people will respond and act in various circumstances.

Many organizations acknowledge that they are working on incorporating AI and ML technologies into their processes to glean better understandings of what is taking place. One benefit of AI is that it will help human beings analyze their behavior and its interrelationship to other dynamics.

The incorporation of AI and ML techniques allows organizations to use the data from customer habits to learn and respond to various and changing conditions. Past statistical data models are compared to present operating conditions, and adjustments are made to optimize (**Figure 3**).

Building lighting control and automation demands are continually changing, a dynamic process of give and take. Past data usage, when combined with simulations performed of potential forecasted demand consumption, may benefit from AI reinforcement models. Organizations wanting to maximize productivity and reduce costs are incentivized to attempt to achieve an economic edge. The overwhelming complicated data of the past in combination with the forecasted models provides a real-time flexible answer to meet today's needs. Because AI is learning, it is continually improving its performance. The sooner one adopts AI and incorporates it as part of the building lighting control and automation process, the sooner it will reach its optimal decision and response level. Flexibility stays inherently high because the AI has learned what and how to adjust the building lighting control and automation variables in response to deviations from optimal performance. The result is that after its adoption, the system's overshoot is damped and mitigated.

Dramatic changes in usage are also handled. Since the system has learned from a variety of conditions how to respond, any significant increases or decreases in various inputs are handled with first order close and approximately correct responses and then further tuned based on reinforcement feedback. The upshot is that the AI system provides a well-controlled, self-correcting, fully automated, decision-making tool to control building lighting.

Office Automation

AI helps make things automated, meaning it enables systems to operate while requiring little or no direct human supervision or control, which means being able to better commission building lighting control and automation to save money, reduce energy consumption and waste, and thus improve the level of service quality and customer satisfaction. A good example of AI in an office setting would be building lighting control and automation changes being implemented as the location of the sun changes throughout the day in synchronization with the measured amount of illumination being received from the sun and adjusted for various locational and output illumination requirements needed by multiple consumers.

Conclusion

While new advances in technology can seem scary for many, I ain't afraid of no ghosts. We do not need to be fearful of AI. With its arrival, AI will enable the commissioning of building lighting control and automation. AI will assist us in moving in a positive direction to save money, reduce energy consumption and waste, improve the level of service quality, and increase customer satisfaction. And that isn't some imaginary ghost story. ■