

Enabling the next generation of video doorbells



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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.

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 personal 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 electronic package that's only a few inches wide challenges design engineers, who not only have to 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 close-circuit television and human observation. With video/audio doorbells hitting the consumer market, however, 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 identify 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 very simple 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: their small form factor, which limits the processing power and storage; and the success of community watch

organizations benefiting from connected doorbell apps. 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 simply to confirm the receipt of packages), enabling cloud connectivity enables a wealth of user functions, while 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 necessary 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 hardline to the front door is always an option. Given the amount of homes and apartments that are 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 be installed.

Power over Ethernet

For newer homes and those willing to do some minor renovations to enable the latest smart-home technology, PoE can enable a single-wire installation for a relatively high-performance video doorbell. Many of the latest 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 solid and secure hardline communications as well as up to 100 W 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 aren't 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 don't 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 are used in both active power systems and complete Wi-Fi systems, where intelligent charging and seamless power transition/supplemental power are key 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 common 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 is often 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 simple method called a passive infrared (PIR) detector. PIR detectors are common in motion-detector lights used for security illumination;

however, this method is limited to warm objects such as people and large animals. In order to avoid false alarms, PIR sensors are 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 outside conditions. For example, ambient light sensors help image-processing algorithms properly adjust the video exposure based on the outside light. Other common 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 certainly 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 primarily powered up with 8 V-24 V transformers rated from 5 VA-30 VA. With the availability of PoE, higher power demands of video doorbell can be met as the latest IEEE standard allows up to 71 W 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 can be 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 significant 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 isn't easily accomplished, though, especially 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. Because 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 that has good receiver sensitivity and low-phase noise to operate in areas with poor reception. Although a typical video doorbell should have at least 1 Mbps of bandwidth, a high-end video doorbell or a video doorbell that suffers from a poor connection may require as much as 3 Mbps.

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 simply 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, even saving 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 enough 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 are often reviewed on their ability to pick up clear audio from intended parties. So it's essential that a video doorbell can determine the direction of a speaker or event with respect to 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 own 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 is 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 app, 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 specifically 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 greater 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.

Additional resources

- [Learn more about TI's video doorbell support](#)
- [Read about the 'new era in speech processing'](#)
- [Find out the top three qualities to consider when designing video doorbells](#)

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