Powering Next-Generation Smart Medical Devices with AI-Optimized MCUs

Continuous glucose monitors allow people with diabetes to receive timely updates on blood sugar values, supporting treatment choices, daily activities, and quality of life.
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Diabetes, a condition that affects over 400 million people globally, requires careful management of blood glucose levels to prevent serious health complications. Continuous glucose monitors (CGMs) and insulin pumps simplify diabetes care by providing real-time data and, in some cases, automated insulin delivery, improving patients' clinical outcomes and quality of life.

Enabling these smart medical devices are microcontroller units (MCUs) with precise sensing, complex data processing, and wireless connectivity in tiny, power-efficient packages. These small-footprint ICs combine processing cores, memory, and various peripherals into a single chip, allowing designers to create highly functional, miniaturized devices.

As the demand for smarter and more power-efficient medical devices ramps, MCUs are evolving to offer advanced functions like AI/ML acceleration, ultra-low-power operation, and multi-protocol connectivity. This case study explores the role of MCUs in CGMs and insulin pumps and outlines Alif Semiconductor's AI-optimized MCUs for next-generation wearables.

CGMs: Real-Time Tracking of Blood Glucose Levels

Continuous glucose monitors are wearable devices that use a small sensor inserted under the skin to measure glucose levels in the interstitial fluid (found in the spaces between cells). By providing real-time, continuous data, CGMs help wearers track trends, detect highs and lows, and make informed decisions about their insulin dose, meal planning, and overall physical activity. The advantages of CGM technology are well-documented, with studies showing improved glycemic control, reduced risk of hypoglycemia, and better quality of life for people with diabetes.

MCUs are a key enabling technology behind the advanced capabilities of modern CGMs. At the most basic level, the MCU is responsible for sampling the glucose sensor and converting analog signals to digital data–tasks requiring precise analog-to-digital converters (ADCs) and signal conditioning circuitry for accurate, low-noise measurements.

Beyond data acquisition, the latest MCUs can run complex algorithms to analyze the raw sensor data and extract meaningful insights. This includes signal processing techniques, such as filtering and calibration to improve the accuracy, as well as predictive algorithms to detect trends and give early warning of impending highs or lows. Some advanced CGMs even incorporate machine learning models that can adapt to an individual user's glucose patterns over time.

Wireless connectivity is another crucial feature of CGMs, allowing users to view their glucose data via an app and share it with healthcare providers. MCUs typically use Bluetooth Low Energy (LE) for communicating with nearby devices and provide the necessary protocol stack and security features to enable secure data transfer. This is made possible via dedicated profiles such as the Continuous Glucose Monitoring Profile (CGMP) and the Glucose Profile (GP) that enable monitoring and measurement of glucose in the user's bloodstream as well as other health profiles such as Pulse Oximeter (PLXP), Heart Rate Profile (HRP), Blood Pressure (BPP) and many more.

Power management is critical in CGMs, which need to operate continuously for multiple days on a tiny, disposable battery. Thus, these devices require power management features, such as dynamic voltage and frequency scaling (DVFS), low-power sleep modes, energy-efficient peripherals, and more to extend battery life without compromising performance.

Insulin Pumps: Automated Insulin Delivery for Glucose Control

Insulin pumps are small, wearable devices that deliver precise doses of insulin throughout the day, replacing the need for multiple daily injections. Combined with CGM data, some insulin pumps can form a closed-loop system that automatically adjusts insulin delivery based on real-time glucose readings, mimicking the function of a healthy pancreas.

This advanced form of therapy, known as automated insulin delivery (AID) or "artificial pancreas" technology, has been proven to significantly improve glucose control, minimize the risk of hypoglycemia, and ease the burden of diabetes management.

Within every insulin pump is an MCU that handles the complex tasks of dosage calculation, pump control, and user interaction. The MCU continuously monitors a user's glucose levels, either through a built-in CGM or by wirelessly communicating with an external CGM device. Based on this data, along with user-input parameters like carbohydrate intake and physical activity levels, the MCU runs algorithms to determine the appropriate insulin dose.

Dosage calculation is a critical safety function that requires high accuracy and reliability. The MCU must implement fault-tolerant algorithms that can detect and compensate for sensor errors, pump malfunctions, or an unexpected change in insulin sensitivity. Advanced pumps may even include adaptive algorithms and artificial intelligence that can learn from previous performance and adjust dosing parameters over time. Once the correct dose is calculated, the MCU must control the pump motor to precisely deliver the right amount of insulin. This requires a careful calibration

Image credit: Adobe Stocks

of pump mechanics and closed-loop control algorithms. The MCU also monitors the pump for occlusions, leaks, or other faults, triggering alarms to alert the user of any issues.

Like CGMs, insulin pumps require wireless connectivity to communicate with other devices and share data. Bluetooth technology allows the device to communicate with a paired device such as a smartphone, allowing the users to view pump status, adjust settings, and receive alerts.

User interaction is another crucial function of the MCU in an insulin pump. Devices will typically include a display, buttons, or a touchscreen for wearers to input data, view settings, and receive alerts. Some devices even offer voice control or integrate with smartwatches for added convenience. Thus, MCUs must be powerful enough to handle all aspects of the user interface, from rendering graphics to processing input events.

Incorporating MCUs into Medical Wearables: Balancing Performance, Size, and Power Efficiency

While MCUs offer tremendous benefits for smart, connected diabetes management devices, engineers and designers must carefully balance trade-offs in performance, size, and energy efficiency. Medical devices have strict constraints on physical dimensions and weight to optimize patients' comfort and ease of use. Solving for this constraint requires the use of highly miniaturized components, including the MCU and its associated memory, sensors, and power management circuitry.

At the same time, performance requirements for these medical devices are increasing—data processing, algorithmic decision-making, and advanced security features all demand significant computational power. As CGMs and insulin pumps become autonomous and more intelligent, they will rely on powerful, energy-efficient MCUs to handle tasks like sensor fusion, anomaly detection, and predictive analytics.

Accuracy and reliability are critical in medical devices, as even slight errors can have serious or life-threatening consequences for patients. Thus, MCUs used in medical applications must undergo rigorous testing and validation to ensure they meet industry standards for precision and fail-safe operation. Testing and validation procedures for MCUs in medical devices will involve a range of simulated conditions, such as extreme temperatures, humidity levels, and electromagnetic interference (EMI).

Integrating wireless connectivity into medical devices like CGMs and insulin pumps adds a new layer of complexity to the design process. The wireless spectrum is congested, with new technologies operating in similar frequency bands. Crowding can lead to interference issues, which can compromise the reliability of communications between medical devices and monitoring or control interfaces.

To address these challenges, manufacturers must turn to wireless protocols suited to the medical industry. Additionally, they must plan for changes in wireless technology, implementing flexible systems that can be updated or reconfigured to adapt to evolving standards and spectrum allocations.

Power management is another key consideration in wireless medical devices, particularly for products that rely on battery power. Intelligent power management systems within the MCU such as DVFS, selective activation of components, and optimized sleep modes can balance energy conservation with continuous operation in everyday use.

Lastly, data security is crucial in any connected medical device. With the rise of cyberthreats, MCUs require strong encryption, secure boot, and hardware-based key storage to safeguard sensitive patient data. These mechanisms enable devices to comply with industry regulations like HIPAA to ensure patient privacy and data confidentiality.

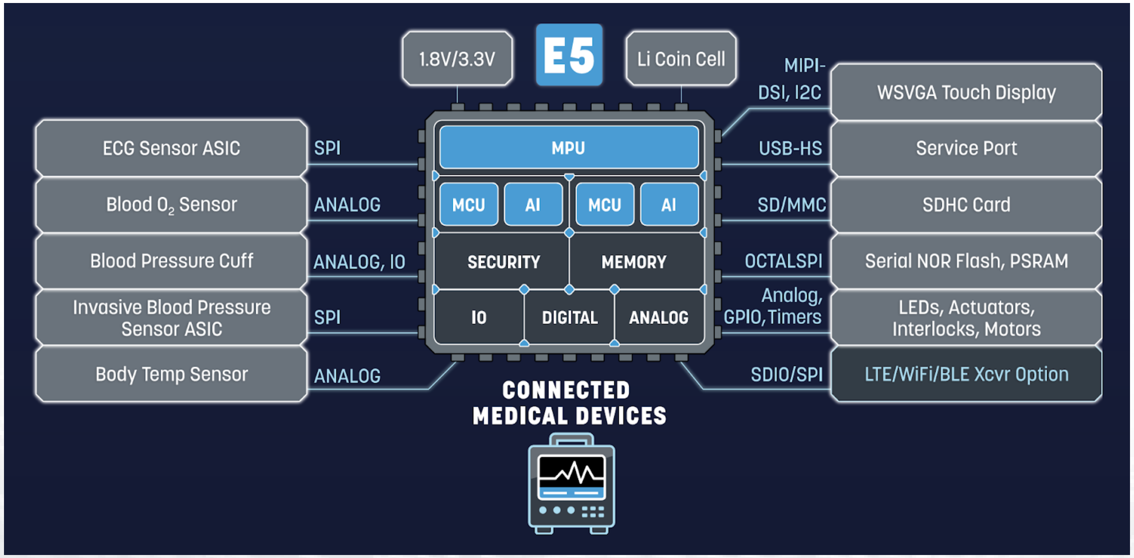
Alif Semiconductor's AI-Enabled MCUs for Smart Medical Devices

Alif offers a range of solutions tailored to the unique demands of the healthcare industry. The Ensemble® Arm®-based MCU family provides the performance, flexibility, and integration for advanced diabetes management solutions, while Balletto™ adds on wireless connectivity.

Alif's Ensemble MCUs are built on a scalable, heterogeneous architecture that combines up to two Cortex®-M55 cores for real-time processing, up to two Cortex-A32 cores for high-level applications, and up to two Ethos™-U55 microNPUs for AI acceleration. This versatile platform enables developers to create intelligent, adaptive medical devices that can handle complex sensor fusion, data analytics, and decision-making tasks with ease.

A key advantage of Alif's Ensemble MCUs is the exceptional AI performance, with up to 250 GOPS of dedicated neural processing power. This performance allows CGMs and insulin pumps to run sophisticated ML models directly on the device, enabling real-time analysis of sensor data, trend prediction, and anomaly detection without relying on a cloud connection. By processing data locally, devices can respond quickly to changing conditions and provide more accurate, personalized insights to users.

In addition to AI capabilities, Ensemble MCUs offer comprehensive functional integration that simplifies the device design and reduces component count. High-precision analog interfaces, flexible display and camera interfaces, and multi-core processing capabilities enable a single MCU to handle multiple aspects of sensing, processing, control, and connectivity. This level of integration not only saves board space, but reduces power usage and improves reliability.

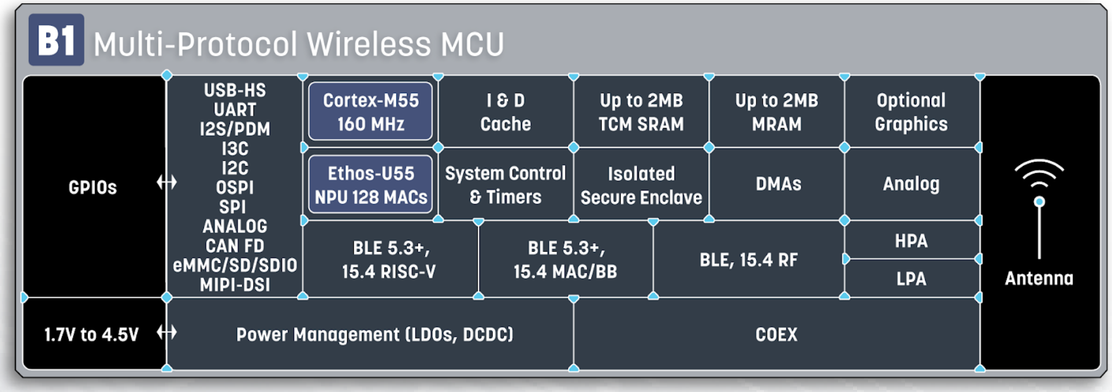


Block diagram of E5 Series fusion processor in a medical application. Image credit: Alif

Alif's Balletto family takes the capabilities of Ensemble further, adding integrated wireless connectivity. With BLE 5.3 radio and support for 802.15.4 protocols, e.g., Zigbee and Thread, Balletto MCUs are suited for CGMs, insulin pumps, and other medical devices that require low-power, short-range communication. The integrated radio minimizes the need for external components, simplifying design and reducing overall system cost.

The Balletto family of MCUs also feature hardware acceleration for AI/ML models and vector extension for DSP that are particularly well-suited for medical applications. The Arm Ethos-U55 NPU provides up to 256 MAC/cycle for efficient execution of neural networks, while a Helium vector extension to the Cortex-M55 enables fast, low-power processing of sensor data and other tasks.

Another key benefit of Balletto MCUs is optimized power management. Alif's Autonomous Intelligent Power Management system, aiPM™, intelligently manages the various subsystems and peripherals, turning off unused components and adjusting the clock speeds based on workload. This fine-grained control over power domains allows Balletto MCUs to achieve very high energy efficiency, with sleep currents as low as 30 nA and active power consumption of just 27 μA/MHz.



B1 series Balletto MCU from Alif Semiconductor. Image credit: Alif

All Alif MCUs incorporate holistic security features to protect sensitive patient data and ensure regulatory compliance. Secure boot, cryptographic accelerators, and tamper detection mechanisms help to prevent unauthorized access and ensure integrity of the device firmware.

Bluetooth technology allows insulin pump users to control treatment options, settings, and alerts wirelessly. Image credit: Shutterstock

Conclusion

As the prevalence of diabetes continues to rise globally, there is a need for more advanced, user-friendly tools to help patients manage the condition. Continuous glucose monitors and insulin pumps are transforming the lives of countless individuals by providing real-time data and automated insulin delivery. With intelligent sensor fusion, real-time data analytics, and predictive algorithms, AI-enabled MCUs, such as Alif's Ensemble and Balletto families make diabetes management more efficient, secure, and personalized.

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If you are interested in learning more about Alif Semiconductor's Ensemble and Balletto families of MCUs, Alif offers evaluation kits, documentation, software & tools, and support resources. To discuss your specific application requirements, please contact Alif Semiconductor's sales team online or email sales@alifsemi.com.