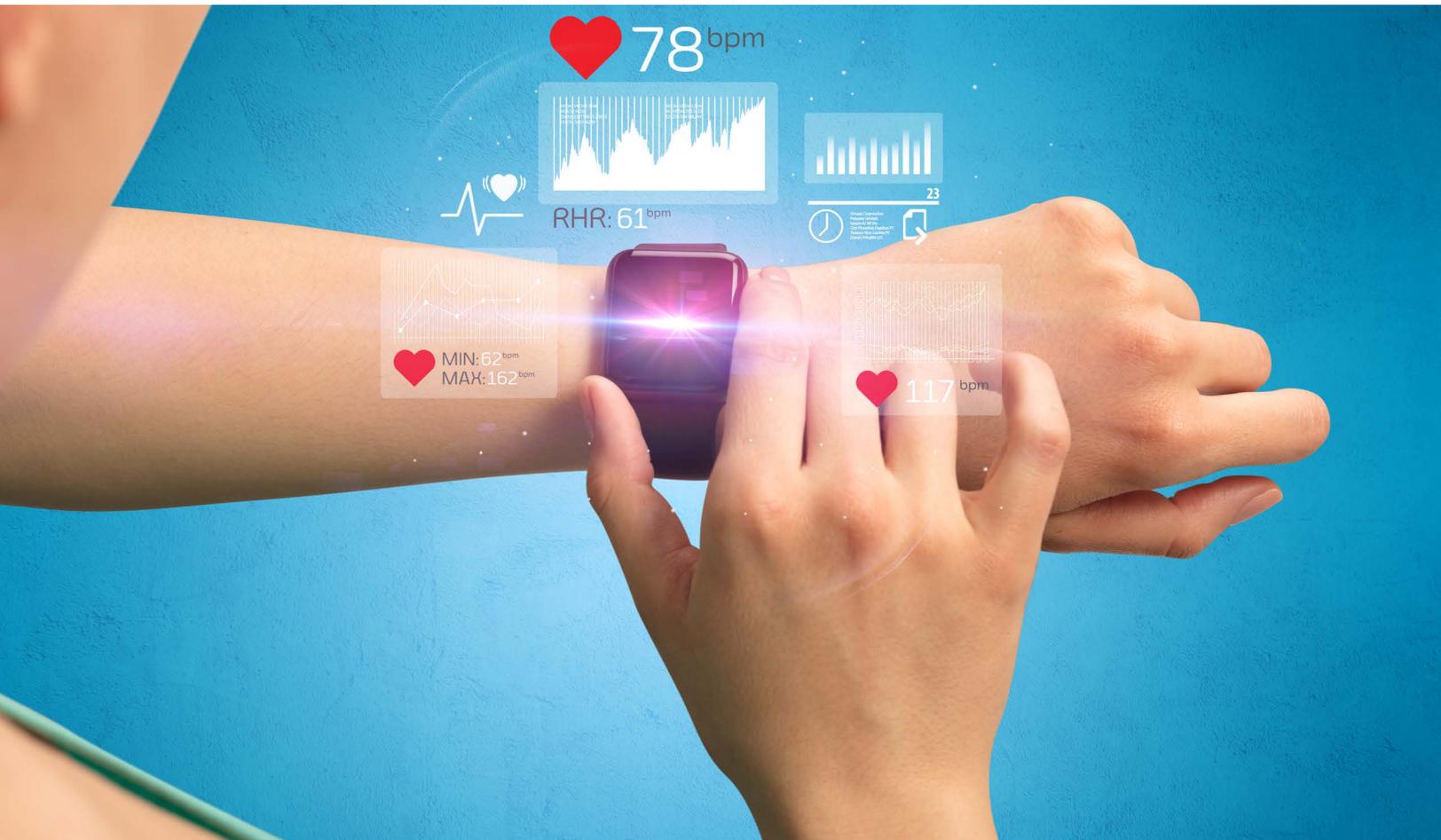


WHITE PAPER

# Harnessing Human Signals: Ultra-Low Power AI at the Edge



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## The Richness of Human Body Data

The human body generates a tapestry of nuanced data every moment. An electrocardiogram (ECG) isn't just a heartbeat graph—its fine-grained patterns carry subtle clues about cardiovascular health and even systemic conditions<sup>1</sup>. In fact, recent AI research shows that machine learning models can discern ECG signal patterns that are far more complex and subtle than even expert cardiologists can interpret<sup>1</sup>. As one cardiologist noted, "The AI model detects much more subtle detail, so it can 'spot' problems in ECGs that would appear normal to us—potentially long before the disease fully develops<sup>1</sup>."

Similarly, voice tone and speech conceal biomarkers of health. Voice recordings, examined by artificial intelligence, may provide new biomarkers for conditions such as heart disease and Alzheimer's<sup>2</sup>. Even seemingly minor daily temperature fluctuations hold meaning. Continuous body temperature tracking has proven more insightful than one-off readings—for example, a smart ring monitoring temperature can foreshadow illness (such as COVID-19) days in advance, whereas spot-check thermometers often miss such subtle changes<sup>3</sup>.

As researchers observed, "single-point temperature measurement is not very meaningful... continual temperature information can better identify fever", accounting for each person's baseline and daily variation<sup>6</sup>. These examples underscore an essential point: our bodies are constantly signaling valuable information. The challenge—and opportunity – is to capture and interpret this rich data to unlock insights that improve health, wellness, and user experiences.

## Simple Sensors, Powerful Data Capture

Capturing human-centric data no longer requires exotic equipment. Modern sensor technologies are remarkably simple and accessible yet capable of gathering rich biometric information. Tiny microphones capture voice and acoustics, electrodes pick up electrical signals (such as ECG from the heart or EEG from the brain), inertial measurement units (IMUs) detect movement and orientation, and photodiodes gauge light changes for pulse oximetry or to monitor ambient conditions. Today's wearable devices routinely integrate multiple sensors—temperature sensors, accelerometers, optical photoplethysmography sensors, and other biosensors—to continuously monitor various human signals<sup>4</sup>.

<sup>1</sup>AI model can predict health risks, including early death, from ECGs | Imperial News | Imperial College London  
<https://www.imperial.ac.uk/news/257300/ai-model-predict-health-risks-including/>

<sup>2</sup>AI listens for health conditions  
[https://www.nature.com/articles/d41586-025-01598-8?error=cookies\\_not\\_supported&code=1741eb82-8681-47c8-a9f7-314cd78cbbce](https://www.nature.com/articles/d41586-025-01598-8?error=cookies_not_supported&code=1741eb82-8681-47c8-a9f7-314cd78cbbce)

<sup>3</sup>Wearable sensor may signal you're developing COVID-19 — even if your symptoms are subtle | University of California  
<https://www.universityofcalifornia.edu/news/wearable-sensor-may-signal-youre-developing-covid-19-even-if-your-symptoms-are-subtle>

<sup>4</sup>Machine Learning for Healthcare Wearable Devices: The Big Picture - PMC (<https://pmc.ncbi.nlm.nih.gov/articles/PMC9038375/>)

Thanks to advances in sensor miniaturization and cost reduction, these components are ubiquitous in smartwatches, fitness bands, rings, and even clothing. Over the past few years, medical-grade sensors have become small and affordable enough to be embedded in consumer wearables, spurring a wave of new applications<sup>5</sup>. A single wearable can thus record a constant stream of multi-modal data throughout a user's day.

This abundance of raw data—encompassing heart rhythms, motion, voice, and temperature—forms a foundation for more in-depth analysis. On its own, however, data is just data. The real value emerges when we derive meaning from it, which is where intelligent processing becomes critical.

Figure 1: Even compact wearables, such as smart rings, contain an array of miniaturized sensors (e.g., optical and inertial sensors) to gather continuous physiological data.



## AI: The Key to Unlocking Insights

Making sense of complex biometric data streams requires more than traditional signal processing—it demands artificial intelligence (AI). The pattern recognition and learning capabilities of modern AI are essential to interpreting data as nuanced as human biometrics. Wearable sensors generate a "big data" problem: multiple signals, high frequency, and individual variability. Machine learning algorithms excel at extracting meaningful features from this flood of information<sup>6</sup>.

<sup>5</sup>Machine Learning for Healthcare Wearable Devices: The Big Picture - PMC (<https://pmc.ncbi.nlm.nih.gov/articles/PMC9038375/>)

<sup>6</sup>Wearable sensor may signal you're developing COVID-19 — even if your symptoms are subtle | University of California  
<https://www.universityofcalifornia.edu/news/wearable-sensor-may-signal-youre-developing-covid-19-even-if-your-symptoms-are-subtle>

In healthcare wearables, AI-based analysis can detect and learn useful patterns related to fitness, stress, disease, and more<sup>7</sup>. For example, AI models have been trained on millions of ECGs to identify hidden markers of cardiac risk that physicians might overlook, enabling predictions of conditions such as arrhythmias or even a patient's 10-year mortality risk from what appears to be a "normal" heartbeat signal<sup>8</sup>.

AI can similarly analyze voice data to infer emotions or cognitive impairment and combine data from multiple sensors to recognize events such as falls or seizures. Crucially, many of these insights were impractical before the rise of modern AI techniques—the patterns are too complex, the data too high-dimensional for manual or rule-based analysis. Today's AI (including deep learning) is the engine that converts raw sensor outputs into actionable intelligence.

By training on large datasets, AI algorithms can detect subtle anomalies, trends, or correlations (such as a slight elevation in nighttime body temperature over several days that signals brewing illness) that would otherwise remain invisible. In short, AI unlocks the value hidden in the rich data our bodies generate<sup>8,9</sup> transforming thousands of data points per second into meaningful insights for health and performance.

## Real-Time, Private, and Secure Data Processing

When dealing with personal health and biometric information, how and where the data is processed is paramount. Real-time analysis is often critical—if a wearable detects an arrhythmia or a fall, it must alert the user (or caregiver) immediately, not after minutes of cloud processing. This necessitates on-device or edge computing to analyze data instantaneously at the source.

Equally important are privacy and security. Biometric data is highly sensitive; users and regulators rightly demand that it be handled with care. Processing data on the device itself means far less information needs to be sent over networks, dramatically reducing exposure risks. In fact, edge computing "can reduce data transmission to the cloud and consequently reduce power consumption and improve privacy by analyzing sensitive private data locally<sup>7</sup>." By keeping data on the device (or on a nearby gateway, such as a smartphone) and transmitting only minimal insights or alerts, we minimize the risk of personal data leaks.

Local processing also allows devices to function without reliable connectivity—a critical factor for health monitors that must work anywhere, anytime. Moreover, modern edge devices are designed with security features to protect data at rest and in use. Techniques such as hardware

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<sup>7</sup>Machine Learning for Healthcare Wearable Devices: The Big Picture - PMC (<https://pmc.ncbi.nlm.nih.gov/articles/PMC9038375/>)

<sup>8</sup>AI model can predict health risks, including early death, from ECGs | Imperial News | Imperial College London  
<https://www.imperial.ac.uk/news/257300/ai-model-predict-health-risks-including/>

<sup>9</sup>AI listens for health conditions  
[https://www.nature.com/articles/d41586-025-01598-8?error=cookies\\_not\\_supported&code=1741eb82-8681-47c8-a9f7-314cd78cbbce](https://www.nature.com/articles/d41586-025-01598-8?error=cookies_not_supported&code=1741eb82-8681-47c8-a9f7-314cd78cbbce)

encryption, secure boot, and trusted execution environments ensure that personal data remains private and secure on-device<sup>10,11</sup>.

For example, some of today's microcontrollers incorporate Arm® TrustZone® and even physical unclonable functions to create a hardware-isolated, trusted zone for sensitive code and data<sup>11</sup>. By analyzing biometric data in real-time on secure local hardware, we achieve a trifecta: immediate insights, data privacy, and robust security. This approach fosters user trust and meets stringent regulatory requirements, making advanced wearables viable in both healthcare and consumer markets.

Figure 2: Analyzing biometric data in real-time on secure local hardware concept.



## Ultra-Low-Power AI at the Edge is Paramount

To realize this vision of real-time AI on wearables and mobile devices, one challenge looms above all: energy efficiency. Power consumption is the foremost limitation for any battery-powered device<sup>10</sup>. Wearables and IoT sensors run on small batteries (or even try to harvest ambient energy), so they must do more with less. If a smartwatch tried to stream raw sensor data to the cloud 24/7 or run heavy computations without optimization, its battery might last only a few hours<sup>10</sup>.

<sup>10</sup>Machine Learning for Healthcare Wearable Devices: The Big Picture - PMC (<https://pmc.ncbi.nlm.nih.gov/articles/PMC9038375/>)

<sup>11</sup>Apollo510 (<https://ambiq.com/apollo510/>)

In fact, continuous monitoring of multiple vital signs can drain a typical wearable device in a few hours if done naively. Clearly, ultra-low-power operation isn't just a nice-to-have—it's absolutely essential for practical wearables. Every aspect of the system must be optimized for efficiency, from the sensors and wireless radios to the algorithms themselves. One proven strategy is to perform as much data filtering and AI inference on-device as possible (a paradigm known as TinyML when applied to microcontrollers). This reduces energy-hungry wireless transmissions and cloud queries. Studies have found that executing machine learning on the device can extend battery life by over 70% by avoiding constant data uploads<sup>12</sup>.

When designing edge AI solutions, developers must consider dedicated low-power hardware for AI, model optimizations (such as quantization and pruning), and intelligent power management. The ultimate goal is "always-on" intelligence: devices that listen, sense and analyze continuously without exhausting their battery. Recent industry trends indicate that this is achievable—wearables now monitor heart activity around the clock or earbud assistants that continually listen for voice commands, all while lasting for days between charges<sup>13</sup>. Achieving this feat hinges on the collaboration of ultra-low-power microcontrollers and efficient AI algorithms. In summary, power is the currency of edge AI, and every milliwatt saved translates to more prolonged use, better user experience, and broader adoption of these life-enhancing devices<sup>12,13</sup>.

## Ambiq's Solution: Efficient and Secure On-Device Intelligence

Meeting the demands of rich sensing, intelligent analysis, privacy, and ultra-low-power operation requires a holistic solution. Ambiq has approached this challenge by reimagining microcontroller (MCU) technology for the era of edge AI. Ambiq's ultra-low-power SoCs, built on the proprietary Subthreshold Power Optimized Technology (SPOT®) platform, drastically reduce energy consumption by operating transistors at sub or near-threshold voltages. The result is a line of processors that deliver the required compute for AI while sipping minimal power.

Figure 3: Analyzing biometric data in real-time on secure local hardware concept.



<sup>12</sup>Machine Learning for Healthcare Wearable Devices: The Big Picture - PMC (<https://pmc.ncbi.nlm.nih.gov/articles/PMC9038375/>)

<sup>13</sup>Why Ultra-Low Power Electronics Are the Way Forward | Ambiq  
<https://ambiq.com/blog/why-ultra-low-power-electronics-are-the-way-forward/>

In fact, Ambiq's Apollo family of system-on-chips consistently leads in energy efficiency. The Apollo4, for instance, "requires a mere fraction of the power" needed by competing System-on-Chip (SoCs), allowing certain smartwatches to run for 21 days on a single charge versus about 5 days with competitors<sup>14</sup>. This leap in battery life—achieved without sacrificing performance—enables continuous health monitoring and always-listening voice interfaces on devices that users don't need to charge every night<sup>14</sup>.

Ambiq's latest fifth-generation chip, the Apollo5 (Apollo510), further pushes the envelope with an Arm® Cortex®-M55 CPU and dedicated vector hardware for AI math. It boasts 3–11 times higher AI processing performance and 4 times better energy efficiency on AI workloads compared to the previous generation, while consuming roughly one-third the power of its nearest competitor in active mode<sup>15</sup>.

Beyond raw efficiency, Ambiq embeds robust security features to protect data on-device. Its SoCs leverage secureSPOT® technology and Arm TrustZone® to establish a Trusted Execution Environment, alongside features such as secure boot, key storage, and even physical unclonable function (PUF) hardware for device authentication<sup>16</sup>. This means that sensitive biometric data and AI models can run in an isolated, encrypted domain, preserving privacy and integrity by design. Developers can confidently deploy health and biometric applications, knowing that both the data and the model are safeguarded on the device.

Ambiq complements its silicon with a growing AI software ecosystem. Through partnerships with platform providers like Edge Impulse, Ambiq makes it easier to develop and deploy machine learning models optimized for its ultra-low-power hardware<sup>17</sup>. As Edge Impulse's CEO notes, "The Apollo4 Plus SoC's ultra-low-power capabilities have made it feasible to deploy incredibly sophisticated AI models efficiently for on-device computing", from wearables to industrial sensors<sup>17</sup>. In other words, Ambiq's solution bridges the gap between cutting-edge AI algorithms and the tight power budgets of mobile devices.

In summary, Ambiq's ultra-low-power MCUs and edge AI software stack directly address the challenges discussed in this paper. By maximizing energy efficiency, they allow continuous, real-time analysis of human signals on tiny batteries. By processing data locally and securely, they uphold privacy while delivering instant insights. Moreover, by providing sufficient compute for modern AI, they ensure that the richness of human body data—from ECG waveforms to voice tones and beyond—can be translated into actionable intelligence right at the edge<sup>14,17</sup>. For SoC purchasers and developers seeking to enable the next generation of smart,

<sup>14</sup>Why Ultra-Low Power Electronics Are the Way Forward | Ambiq  
<https://ambiq.com/blog/why-ultra-low-power-electronics-are-the-way-forward/>

<sup>15</sup> Ambiq Brings Low-Power AI to the Edge | TechInsights (<https://www.techinsights.com/blog/ambiq-brings-low-power-ai-edge>)

<sup>16</sup> Apollo510 (<https://ambiq.com/apollo510/>)

<sup>17</sup> Ambiq and Edge Impulse Enable Low-Power Scalable AI | Ambiq  
<https://ambiq.com/news/ambiq-and-edge-impulse-enable-low-power-scalable-ai/>

health-aware wearables and IoT devices, this approach presents a compelling path forward: intelligent, always-on devices that are both energy-efficient and insightful.

## About Ambiq

Headquartered in Austin, Texas, Ambiq's mission is to enable intelligence (artificial intelligence (AI) and beyond) everywhere by delivering the lowest power semiconductor solutions. Ambiq enables its customers to deliver AI compute at the edge where power consumption challenges are the most severe. Ambiq's technology innovations, built on the patented and proprietary subthreshold power optimized technology (SPOT®), fundamentally deliver a multi-fold improvement in power consumption over traditional semiconductor designs. Ambiq has powered over 280 million devices to date. For more information, visit [www.ambiq.com](http://www.ambiq.com).

*Sources: The statements above are supported by recent research and industry data, including academic studies on wearable AI and power consumption<sup>18</sup> expert commentary on advanced ECG and voice analysis using AI<sup>19,20</sup>, and documented performance metrics of Ambiq's ultra-low-power solutions<sup>21,22</sup>. Each citation is provided to ensure the accuracy and credibility of the claims made.*

<sup>18</sup> Machine Learning for Healthcare Wearable Devices: The Big Picture - PMC (<https://pmc.ncbi.nlm.nih.gov/articles/PMC9038375/>)

<sup>19</sup> AI model can predict health risks, including early death, from ECGs | Imperial News | Imperial College London  
<https://www.imperial.ac.uk/news/257300/ai-model-predict-health-risks-including/>

<sup>20</sup> AI listens for health conditions  
[https://www.nature.com/articles/d41586-025-01598-8?error=cookies\\_not\\_supported&code=1741eb82-8681-47c8-a9f7-314cd78cbbce](https://www.nature.com/articles/d41586-025-01598-8?error=cookies_not_supported&code=1741eb82-8681-47c8-a9f7-314cd78cbbce)

<sup>21</sup> Why Ultra-Low Power Electronics Are the Way Forward | Ambiq  
<https://ambiq.com/blog/why-ultra-low-power-electronics-are-the-way-forward/>

<sup>22</sup> Ambiq Brings Low-Power AI to the Edge | TechInsights (<https://www.techinsights.com/blog/ambiq-brings-low-power-ai-edge>)



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6500 River Place Boulevard, Building 7, Suite 200, Austin, TX 78730

[www.ambiq.com](http://www.ambiq.com)

[sales@ambiq.com](mailto:sales@ambiq.com)

+1 512. 879.2850

A-SOCAPG-WPGA01EN v1.0

August 2025