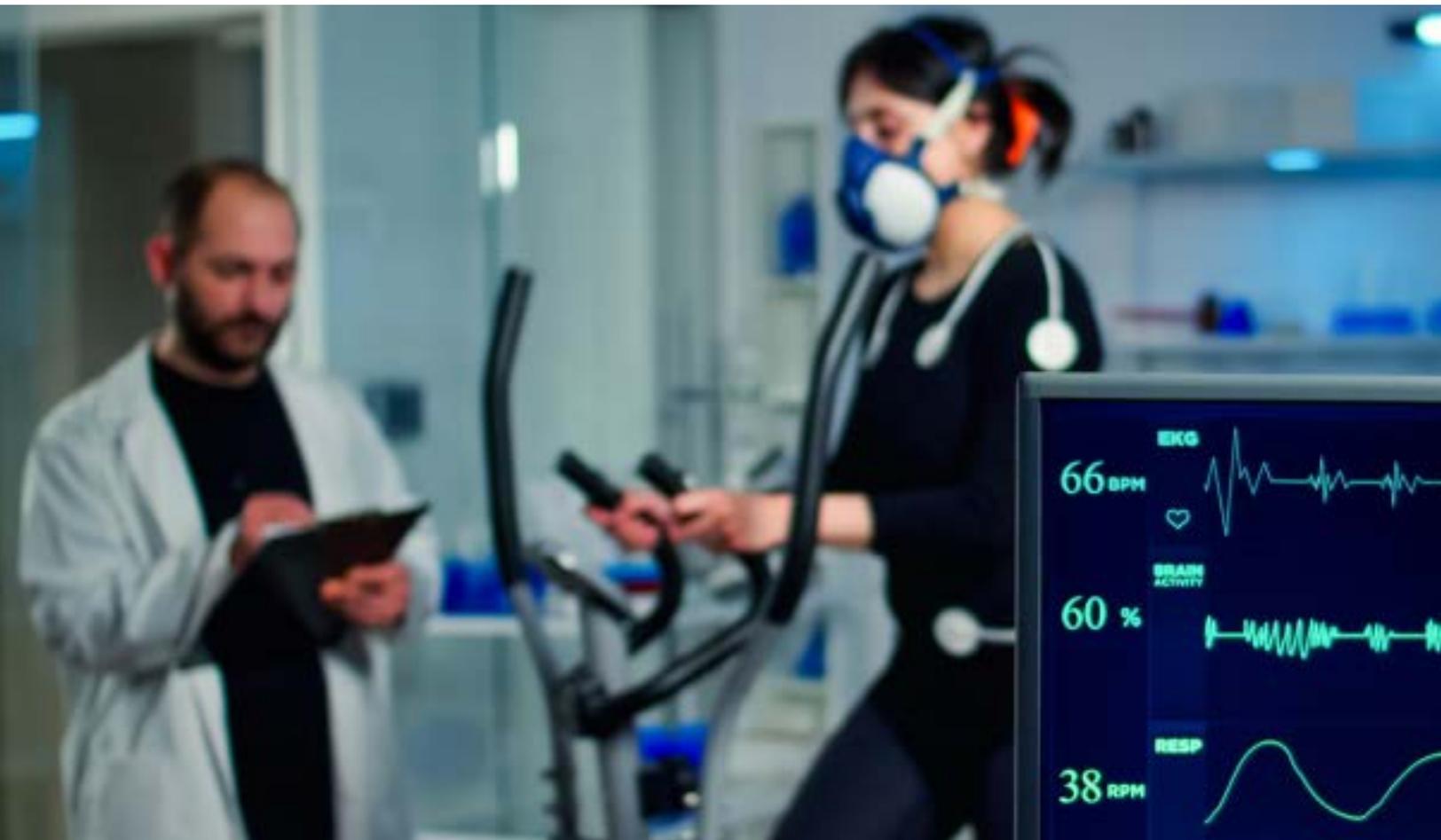




WHITE PAPER

Ultra-Low-Power Biosignal Analytics for Next-Generation Wearables



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Executive Summary

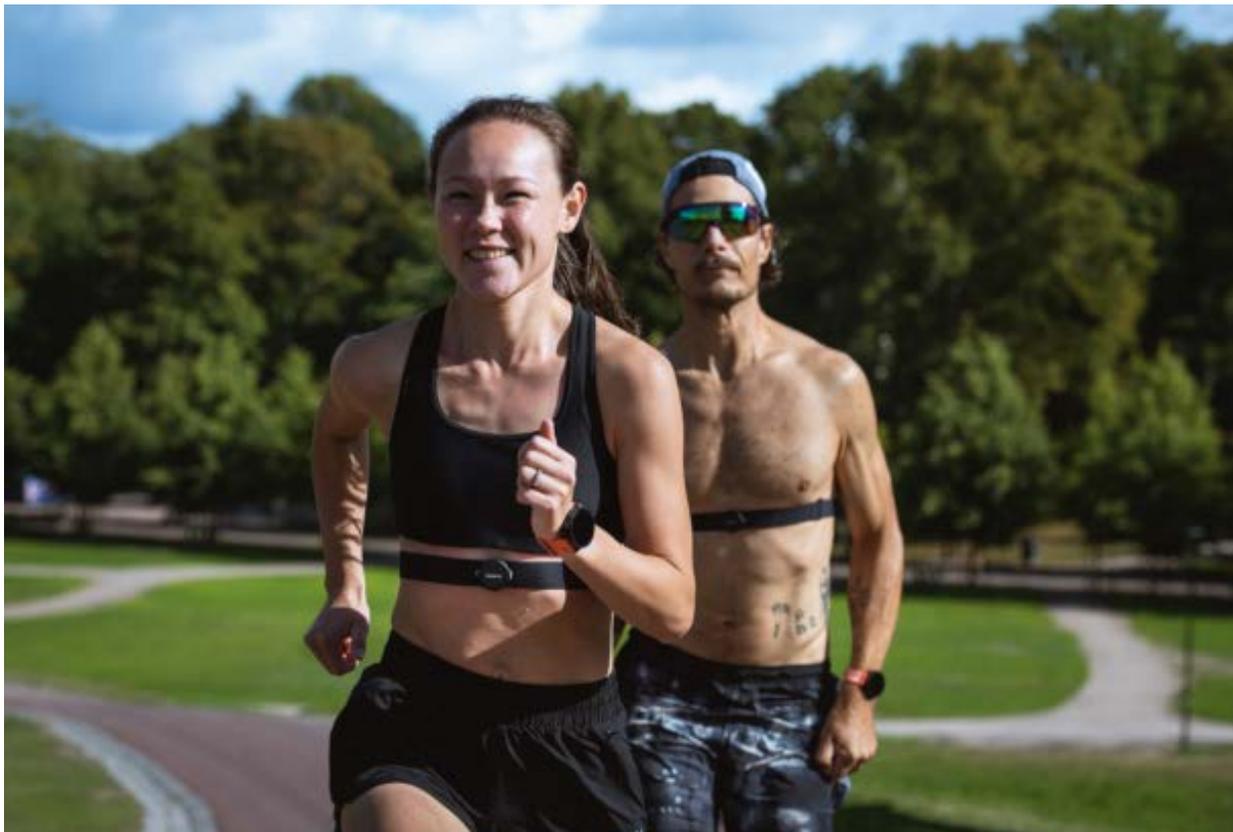
Accurate, real-time assessment of heart function remains one of the most challenging tasks in consumer wearables. Devices today measure heart rate with high precision and can compute a range of heart rate variability (HRV) metrics, providing valuable insights into training, recovery, and overall wellness. Yet these metrics often fall short in practice: they are indirect, inconsistent, and limited in accuracy when applied to real-world conditions. This creates a gap between the data wearables collect and the actionable guidance that athletes, wellness users, and healthcare providers truly need. Bridging this gap requires more advanced analytics that can reveal the hidden complexity in beat-to-beat heart signals and transform raw data into reliable indicators for performance, recovery, and risk prediction.

[MoniCardi](#), a Tampere University spin-out and [ESA \(European Space Agency\) BIC Finland](#) company, has developed patented algorithms that reveal the hidden complexity of beat-to-beat heart intervals, going far beyond conventional HRV metrics. Backed by more than 20 peer-reviewed publications and high-profile research in computational physics and cardiology, these methods provide robust insights into cardiac load, sleep, and recovery that are both scientifically validated and practically applicable.

By leveraging Ambiq's Apollo510 SoC and Subthreshold Power Optimized Technology (SPOT) platform, MoniCardi's algorithm can be implemented into real-world consumer wearables, enabling days or weeks of continuous health analytics on a single charge.

In 2024, Suunto became the first brand to integrate MoniCardi's innovation into its ZoneSense platform, giving endurance athletes access to lab-level intensity measurement during everyday training. Powered by Ambiq's ultra-low-power platform, the MoniCardi software represents a breakthrough approach to how advanced cardiac science can finally run continuously, directly from the wrist. Together, MoniCardi and Ambiq are reshaping the future of wearable health, bringing professional-grade performance metrics to fitness and wellness products that can withstand extreme environments, such as those found in space. This partnership will ultimately shape the future of preventive and medical applications.

Figure 1: Suunto Runs MoniCardi software in their heart rate belt and smartwatches providing continuous health capture powered by Ambiq's Apollo510 SoC



Market Opportunity

In 2025, digital health has become a core pillar of healthcare delivery, valued at over USD 288 billion in 2024 and on track to reach nearly USD 1 trillion by 2030. AI, connected devices, and consumer demand for personalized, continuous care drive growth.

Within this momentum, fitness and wellness are leading adoption. While today's wearables measure heart rate and HRV with high precision, the insights they provide often remain generic and limited in real-world accuracy. Consumers increasingly want actionable guidance on training intensity, recovery, and sleep. MoniCardi addresses this need with algorithms already proven in Suunto ZoneSense, which brings lab-level intensity measurement to the wrist without invasive testing or calibration.

At the same time, the rising global burden of chronic disease, particularly cardiovascular conditions, which are the leading cause of death, has accelerated the shift toward predictive and preventive models of care. MoniCardi's validated, science-based methods are therefore not only relevant for today's fitness and wellness markets but also create a clear pathway toward regulated med-tech applications.

Positioned at the intersection of fitness, wellness, and preventive health, MoniCardi delivers a software-only, hardware-agnostic solution. Combined with Ambiq's proven ultra-low-power Apollo SoCs, it enables continuous, reliable, and energy-efficient monitoring, giving OEM partners a competitive edge in the current market with optimized solutions for edge AI and scalable manufacturing. Together, MoniCardi and Ambiq pave the way for the broader digital health ecosystem of the future.

Figure 2: MoniCardi's algorithms bring lab-level intensity measurement to wearable devices without invasive testing or calibration, already proven in Suunto's ZoneSense



Technology Overview: Advanced Biosignal Analytics

Conventional HRV methods capture statistical fluctuations in beat-to-beat intervals but are limited in describing the deeper, multi-scale correlations that reflect how the heart adapts under different conditions. To overcome these limitations, researchers at Tampere University originally developed Dynamical Detrended Fluctuation Analysis¹ (DDFA), a method designed to characterize correlation properties in heartbeat intervals. Building on this foundation, MoniCardi has further adapted and patented the technology to enable real-time and energy-efficient monitoring of beat-to-beat dynamics and their relation to physiological states².

¹M. Molkari, G. Angelotti, T. Emig, and E. Räsänen, Dynamical Heart Beat Correlations During Running, *Sci. Rep.* **10**, 13627 (2020). <https://doi.org/10.1038/s41598-020-70358-7>

²M. Molkari and E. Räsänen, *Inter-beat Interval sequence of heart for estimating condition of subject*, Patent (pending, 2025).

Through this innovation, MoniCardi's algorithms go beyond conventional HRV by revealing the underlying complexity of cardiac dynamics across multiple time scales. Validation studies have shown that DDFA can accurately identify aerobic and anaerobic thresholds during incremental exercise tests, closely matching lactate-based gold standards without the need for invasive sampling^{3,4}. This enables endurance athletes to obtain precise threshold data directly from wearable devices in real-time. Beyond performance monitoring, the same methods are applied to recovery and sleep, where subtle shifts in autonomic regulation provide a more reliable measure of restorative quality than nightly HRV averages. Clinical research also suggests that these algorithms may detect early risk signatures associated with conditions such as sudden cardiac death⁵ or heart failure⁶, creating a potential pathway toward predictive monitoring in healthcare.

Figure 3: Ambiq's Apollo510 enables ultra-low power efficiency for wearables and other digital health monitoring devices that require high performance and on-device processing



Performance
Apollo510

Arm Cortex-M55 core MCU at 96 / 250 MHz
Helium™ technology AI accelerator at up to 8 MACs per cycle
TrustZone® security with PUF (Physical Unclonable Function)
2D/2.5D GPU with vector graphics acceleration
4MB Embedded NVM
3.75MB Embedded SRAM
USB FS/HS, HSPI, PDM stereo DMIC interface
Available now

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apollo
by ambiq inc.
APOLLO510

³Matias Kanninen, Teemu Pukkila, Joonas Kuisma, Matti Molkari, Kimmo Lajunen, and Esa Räsänen, Estimation of Physiological Exercise Thresholds Based on Dynamical Correlation Properties of Heart Rate Variability, *Frontiers in Physiology* 14 (2023). <https://doi.org/10.3389/fphys.2023.1299104>

⁴Matias Kanninen, Vesa Laatikainen-Raussi, Teemu Pukkila, Krista Vohlakari, Esa Hynynen, Johanna K. Ihalainen, and Esa Räsänen, Estimation of Aerobic and Anaerobic Thresholds in Running Using Dynamical Correlations of Heart Rate Variability, *Physiol. Rep.* 12, e70241 (2025). <https://doi.org/10.14814/phy2.70241>

⁵Jussi Hernesniemi, Teemu Pukkila, Matti Molkari, Kjell Nikus, Leo-Pekka Lyytikäinen, Terho Lehtimäki, Jari Viik, Mika Kähönen, Esa Räsänen, Prediction of sudden cardiac death with ultra-short-term heart rate fluctuations, *JACC: Clinical Electrophysiology* 10, 2010 (2024). <https://doi.org/10.1016/j.jacep.2024.04.018>

⁶Teemu Pukkila, Matti Molkari, Jussi Hernesniemi, Matias Kanninen, and Esa Räsänen, Detection of congestive heart failure from RR intervals during long-term ECG recordings, *Heart Rhythm* O2 6, P509-518 (2025). <https://doi.org/10.1016/j.hrro.2025.01.014>

Running on Ambiq's Apollo510

MoniCardi's software is designed to be hardware-agnostic, but advanced biosignal analytics require efficient real-time processing directly on the device. To meet this need, MoniCardi has optimized its algorithms to run with extremely low current and power demands, making them ideally suited for integration with Ambiq's Apollo510. The Apollo510 delivers the ultra-low power consumption and edge intelligence needed to support continuous cardiac monitoring directly on the device, in real-time. Unlike black-box AI methods, MoniCardi's approach is grounded in analyzing characteristic features of beat-to-beat heart sequences. These features can also serve as inputs for supplementary AI, enabling explainable and transparent AI solutions.

As part of the ESA BIC Finland, MoniCardi has been recognized for its potential to bring advanced signal processing from space research into consumer and medical health monitoring. The affiliation provides access to international networks and highlights the company's credibility in developing technologies for extreme environments. In space applications, as in consumer wearables, minimizing power consumption is a critical requirement. MoniCardi is therefore extending its expertise to algorithmic solutions for sensors intended for space missions, where ultra-low-power operation is essential for the reliability of space-grade components. This dual focus on commercial wearables and space systems underscores the versatility and future-proof nature of MoniCardi's technology when combined with Ambiq's Apollo510 SoC.

Figure 4: Suunto ZoneSense use MoniCardi's algorithms to detect key physiological changes turning beat-to-beat heart interval sequences into personalized, real-time training zones



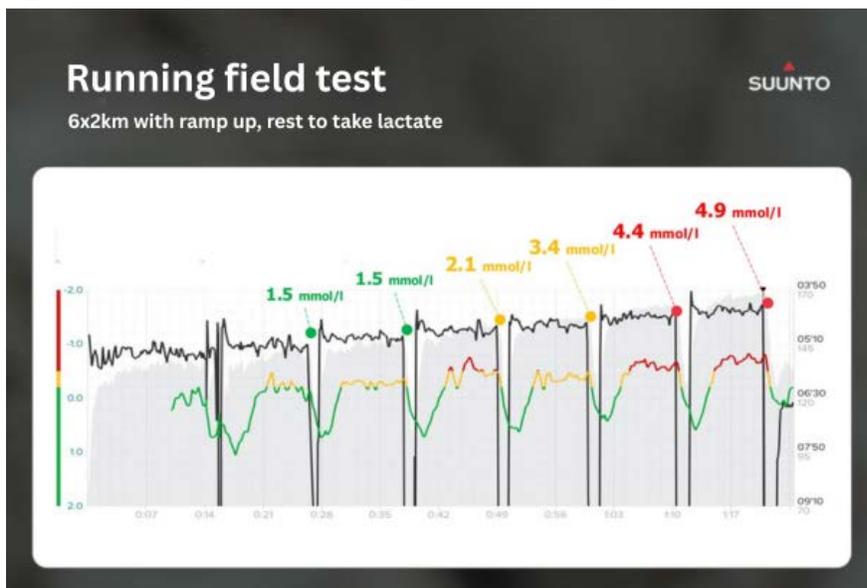
Suunto ZoneSense

Suunto ZoneSense demonstrates how MoniCardi's technology changes training in practice. Conventional smartwatch training zones are based on generic formulas tied to maximum heart rate, which often fail to accurately represent an individual's actual physiology. This makes it difficult to determine the exact training intensity, define personal lactate-based zones, account for daily readiness, or accurately measure recovery. ZoneSense addresses these gaps by detecting key physiological changes in beat-to-beat heart interval sequences and translating them into personalized, real-time training zones.

For the **everyday athlete**, the experience is straightforward, motivating, and simple. The watch automatically displays the current training zone without requiring any prior calibration or maximum heart-rate estimates. This allows users to understand the real effects of their workouts without guesswork, encouraging safe and effective sessions that prevent overtraining. Over time, this builds confidence and consistency in fitness, helping recreational athletes progress with the assurance that they are training in the right way.

For the elite athlete, ZoneSense delivers laboratory-level precision on the wrist. It enables optimization of training intensity for each session by confirming when an easy workout is truly easy, and by flagging if the intensity is drifting too high. During hard intervals, it verifies that the correct physiological zone has been reached, and it helps identify the aerobic and anaerobic thresholds that underpin peak performance. This precision makes it a powerful tool for professional athletes and coaches worldwide who rely on ZoneSense in their training. Figure 5 shows the measured blood lactate concentrations (numeric values) align closely with ZoneSense (colored line) derived using MoniCardi's algorithm from beat-to-beat heart rate intervals. The gray curve represents heart rate, and the black line indicates running speed.

Figure 5: Example field test during interval running



Under the hood, ZoneSense is built on MoniCardi's patented and validated methods, proven in sports science studies. It currently requires the use of a heart rate belt, which enables accurate beat-to-beat data collection across all types of exercise. However, the technology is fully compatible with PPG sensors and other beat-to-beat extraction methods, and can be adapted for such devices upon validation in different sports.

ZoneSense is also lightweight enough to run directly on the watch or even at the chip level. By combining this algorithmic efficiency with Ambiq's energy-efficient Apollo SoC, ZoneSense makes advanced exercise physiology accessible to anyone, allowing for longer intervals between charges—a requirement for both consumer adoption and elite athlete performance. For OEMs, ZoneSense demonstrates how MoniCardi's science can be seamlessly integrated into consumer devices to deliver measurable value to both elite athletes and everyday users.

Outlook and Applications

Today: Fitness & Wellness

MoniCardi's first commercial applications are in the fitness and wellness sector, where the demand for accurate and actionable insights is rapidly growing. Through solutions like Suunto ZoneSense, athletes can now measure training intensity and cardiac load with laboratory-level precision directly from their sports watches, eliminating the need for invasive lactate testing. Beyond performance monitoring, the same algorithms provide reliable assessments of sleep and recovery, offering users a deeper understanding of how daily activity and rest interact to influence overall well-being.

Tomorrow: Preventive Health

Looking ahead, MoniCardi's clinically validated methods are positioned to support preventive healthcare by detecting subtle signs of cardiac risk before symptoms emerge. This includes risk scoring for sudden cardiac events and early identification of conditions such as heart failure and sleep apnea. MoniCardi and Ambiq can help shift the focus of healthcare from treatment to prevention. Enabling continuous, non-invasive monitoring in everyday wearables will help reduce the burden of cardiovascular disease while empowering individuals to take proactive steps toward healthier lives.

Figure 6: MoniCardi is exploring algorithmic solutions for space health and other challenging conditions, such as high-altitude or remote monitoring



Future: Med-Tech and Space

In the longer term, MoniCardi's technology holds promise for regulated medical applications as well as extreme environments. With clinical-grade validation and future certification under MDR and FDA standards, the algorithms could be integrated into medical devices for advanced cardiac risk assessment and patient monitoring. At the same time, as part of its work within the ESA Business Incubation Centre, MoniCardi is exploring algorithmic solutions for space health and other challenging conditions, such as high-altitude or remote monitoring. In these environments, where reliability and ultra-low-power operation are crucial, MoniCardi's technology, combined with Ambiq's Apollo SoC for edge AI, can deliver continuous insights without relying on constant cloud connectivity. This will support human performance and safety beyond the boundaries of conventional healthcare.

Conclusion

By combining MoniCardi's clinically validated biosignal analytics with Ambiq's ultra-low-power Apollo510 SoC, wearable manufacturers can unlock a new generation of smart health features that are accurate, actionable, and energy-efficient. For OEMs, this offers a clear path to stand

out in today's crowded fitness and wellness markets while also laying a foundation for future opportunities in the expanding digital health ecosystem. MoniCardi invites partners to license its software for Ambiq-powered devices and to collaborate in bringing space-incubated, scientifically validated, and ultra-low-power cardiac monitoring solutions to users worldwide.

About MoniCardi

MoniCardi's story began over a decade ago in the Physics Unit of Tampere University, Finland, where research in computational quantum physics evolved into pioneering work in cardiac time-series analytics. Founded in 2024, MoniCardi is now a commercially validated software company partnering with global brands to transform advanced science into life-saving technology. Its patented, physics-driven software delivers clinically relevant insights from any wearable device, enabling accurate, real-time cardiac health monitoring across fitness, wellness, and medical domains. For more information, visit www.monicardi.com.

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.



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