Sonair

How did a team of Nordic researchers manage to build a 3D ultrasonic sensor that provides safe object detection, miniaturization, cost efficiency, and low power consumption compared to other methods for recording 3D information?

Beyond sight

Ensuring safety where vision falls short

Vision alone is not enough

On the night of March 18, 2018, Elaine Herzberg was pushing her bicycle across a dimly lit street in Tempe, Arizona, outside the boundaries of a marked crosswalk, when a Volvo XC90 SUV approached. In the driver’s seat was Rafaela Vasquez, though her hands were not on the steering wheel. The vehicle appeared to be under the control of the autonomous driving system.

As the car closed in on Herzberg, the technology intended to detect and respond to obstacles failed to recognize the imminent danger. In a moment that would later be scrutinized by engineers and investigators alike, the vehicle did not slow down but instead continued forward. The collision that followed claimed Elaine Herzberg's life, making her the first pedestrian to be killed by an autonomous vehicle.

This tragic incident, despite statistical evidence that self-driving cars are generally safer than human-operated vehicles, highlighted the critical importance of safe operation in autonomous technologies. With millions of autonomous robots already deployed in warehouses worldwide and their numbers expected to grow significantly, this event serves as a stark reminder of the need for robust systems that can reliably handle complex, real-world scenarios.

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Content

The need for multisensory perception

Our eyes are arguably the most crucial sensors we have for experiencing the world. We use them for navigation, obstacle detection and avoidance, and helping to maintain our balance. Vision is not the only sense we rely on. From an early age, we learn to listen for the sound of approaching vehicles before crossing the street. We instinctively react to unexpected noises behind us with our ears functioning as safety sensors, that alert us to dangers even when they are not immediately visible.

Some animals have evolved sophisticated ways of using sound to perceive their environment. They use sound not only for hearing but to "see" through echolocation, a technique that enables them to navigate and hunt by analyzing the echoes of sounds they emit. Dolphins, for example, explore the ocean's depths by emitting high-frequency clicks. These clicks bounce off objects and return as echoes, providing dolphins with detailed information about their surroundings, including the distance, direction, size, shape, and even the texture of objects.

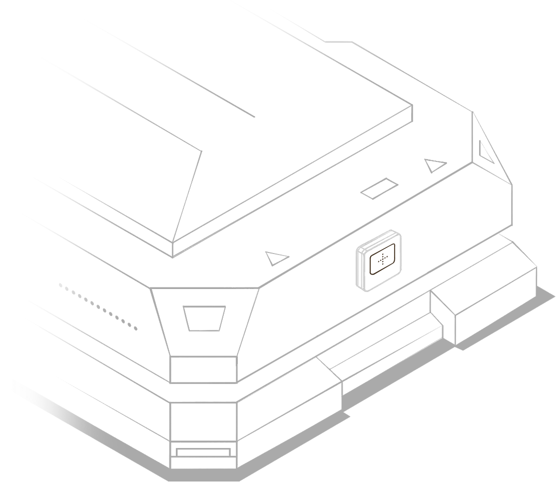
Echolocation has evolved independently across various species. While cetaceans use it underwater, bats and oilbirds rely on echolocation in air to guide their flight. Meanwhile, on land, shrews use echolocation to thrive in their nocturnal rhythm.

The fact that nature has repeatedly evolved echolocation in such diverse environments raises important questions: Would robots benefit from echolocation capabilities? If echolocation provides animals with a proven advantage in navigating the complex challenges of the real world, then would incorporating that capability into robotic systems drastically enhance their ability to operate in environments where vision sensors alone don't suffice?

Bringing 3D ultrasonic sensing to robots

Since its widespread adoption in the 2000s, Light Detection and Ranging (LiDAR) has revolutionized the field of spatial sensing. Over the past two years, Sonair has been developing acoustic detection and ranging (ADAR), an emerging technology that extends LiDAR's principles by using sound waves instead of light.

The basic principle of ADAR operation is analogous to that of LiDAR. ADAR emits sound waves that are reflected by nearby objects and subsequently detected by Sonair's sensor. Yet, the similarities end there. While LiDAR typically relies on a rotating laser beam to scan the environment, Sonair's ADAR can cover a full hemisphere (180° x 180°) without any moving parts. To better understand how this was achieved, we must first explore the workings of acoustic arrays.



Acoustic arrays

Humans are equipped with a built-in acoustic array: our two ears. When we hear a sudden noise, such as rustling grass or a snapping branch, our brains rapidly compute the difference in arrival time between the sound in each ear, known as the interaural time difference (ITD). If the sound reaches both ears simultaneously, the source is directly in front of us. If one ear receives the sound slightly earlier, the brain uses the ITD to predict the sound's angle of arrival. The brain performs this process automatically, without our conscious awareness.

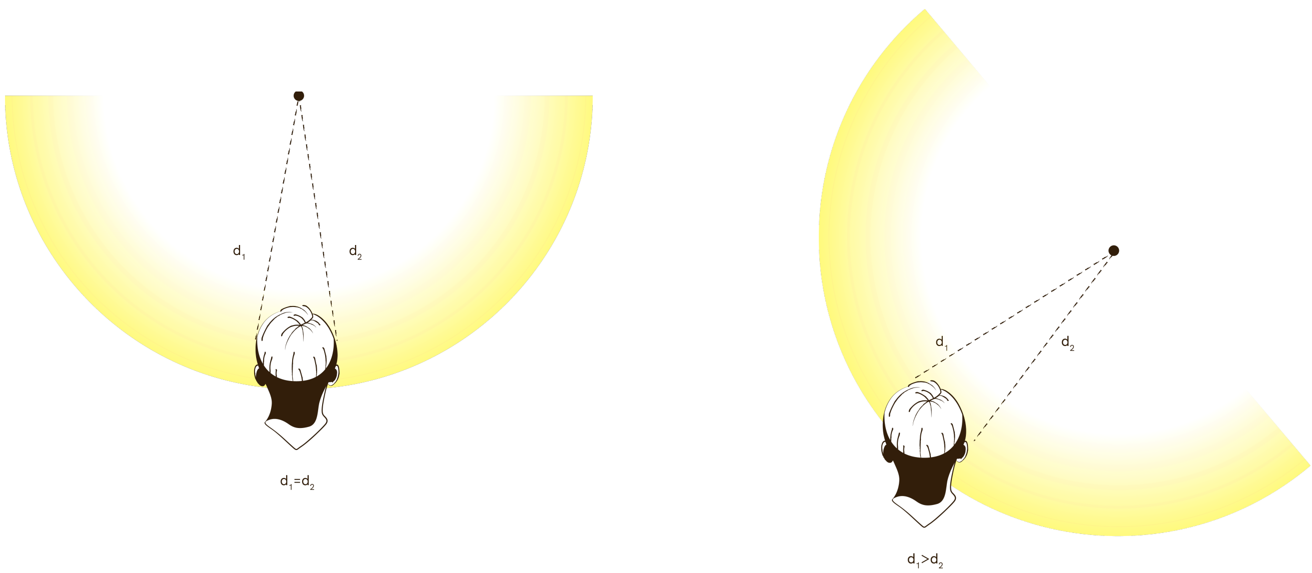


Image 1 Our brains use the interaural time difference (ITD) to infer sound angle of arrival

Our two-element array, however, has limitations that nature has partially mitigated through clever signal processing. For example, rather than requiring a third ear to detect the elevation of sound, the intricate design of our pinna (the visible part of the ear) transforms the sound based on its vertical angle. Over time our brains developed the ability to recognize and interpret these transformations, enabling us to discern the elevation of sound sources.

Ultrasonic arrays, like those used in SONAR and medical imaging, are not bound by these natural limitations. By using an array of ultrasonic sensors distributed over a 2D plane and analyzing the time differences between the signals received by all the sensors, it is possible to determine the 3D angle of arrival and distance.

3D ultrasonic sensing has been widely used underwater and in medical imaging for over two decades, enabling well-known applications like 3D fetal imaging. However, two important challenges have hindered its application in air.

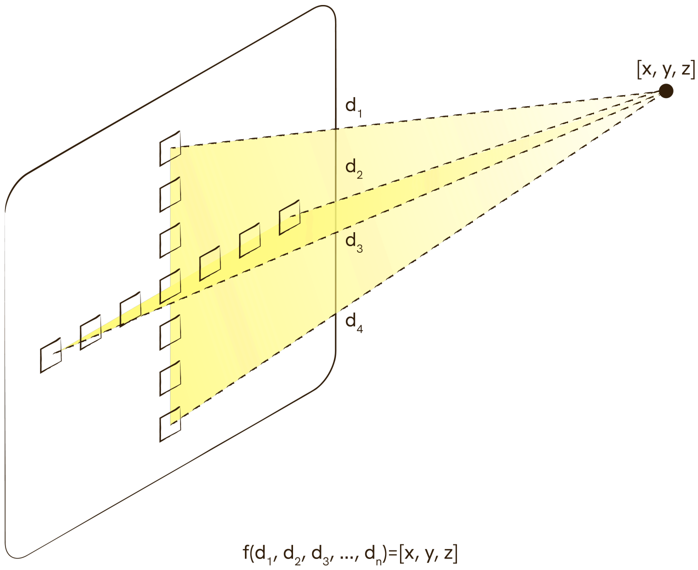


Image 2 By comparing the time of arrival at each element it is possible to estimate the source location

The tyranny of the λ/2 rule

For ultrasonic arrays to accurately determine target positions, the distance between adjacent elements must be less than or equal to half the wavelength of the transmitted sound. This spacing, known as the λ/2 rule, avoids position ambiguity. Using spacing above the λ/2 rule is troublesome since, in more technical terms, extra grating lobes are created.

In water, where sound travels at 1500 m/s, the λ/2 rule requires elements to be spaced no more than 9.4 mm apart for 80 kHz operation—a relatively easy task with the available technology. However, in air, where sound travels at 343 m/s, the same rule demands that elements be spaced no more than 2.1 mm apart for 80 kHz operation. Manufacturing efficient transducers smaller than 2.1 mm was a technological feat beyond reach. Until now.

> In antenna or transducer arrays, if the elements are not sufficiently close together, the resulting large inter-element spacing can cause the radiated or received fields to add in phase along multiple directions.

Meet MEMS

MEMS (MicroElectroMechanical System) technology is used to fabricate miniaturized mechanical systems where the main material is silicon. These can be coupled with microelectronics. The technology is used to make various products such as sensors, actuators, and oscillators. MEMS can also be used to scale down ultrasound transducers to what are known as MUTs (Micromachined Ultrasonic Transducers). One way of doing this is by a piezoelectric material addon to MEMS (piezoMEMS), resulting in a PMUT (Piezoelectric Micromachined Ultrasonic Transducer).

SINTEF MiNaLab has worked strategically with piezoMEMS for 20 years, and in that time both device performance and production maturity/volume have seen huge progress. The result is that PMUTs now show comparable sound pressure with commercial bulk transducers, in air, at a fraction of the size (image 3). A 3x3 100 kHz PMUT array has the same footprint as the smallest commercial transducer. Another benefit is that PMUTs can be designed to transmit at higher frequencies than 40 kHz, which have become the standard for air-based ultrasound. This is beneficial as the angular resolution is fundamentally dependent on the frequency.

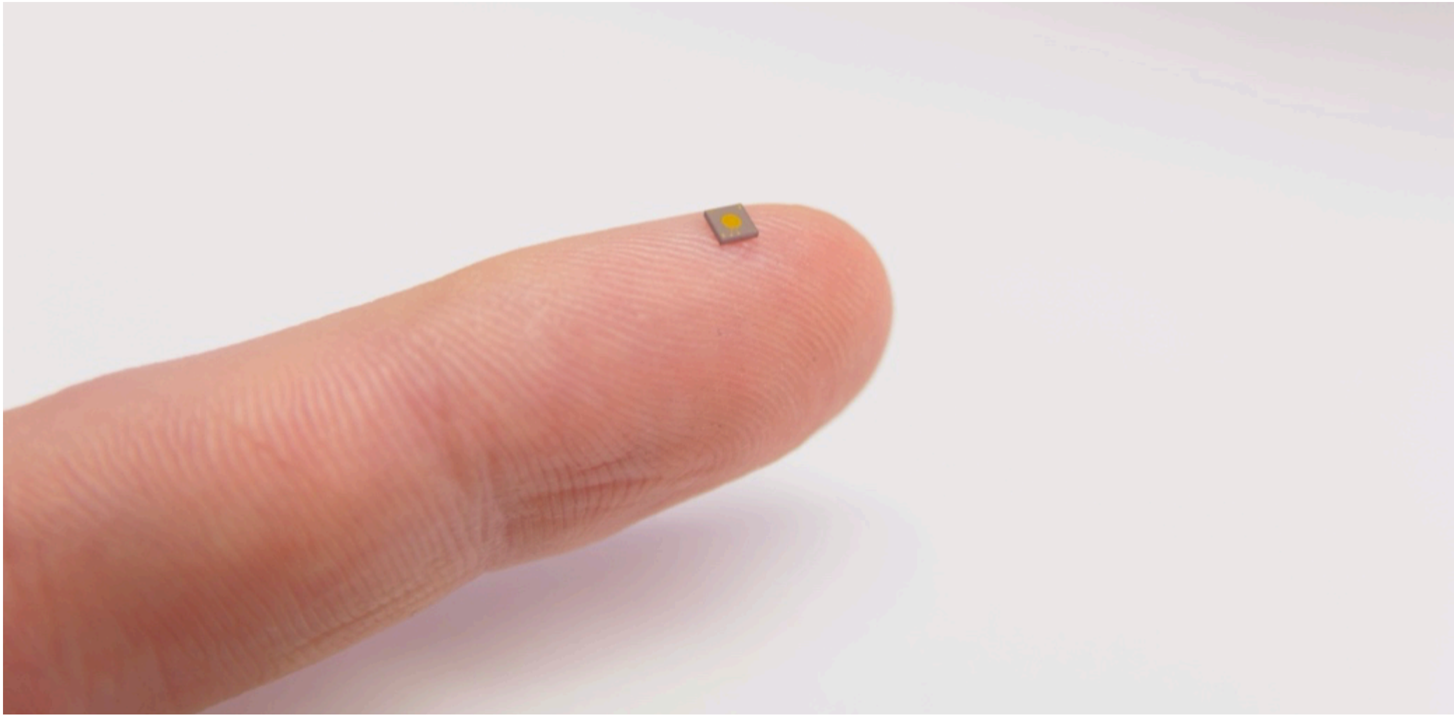


Image 3 : A 2.5x2.5 mm PMUT transducer fabricated at SINTEF MiNaLab

3D beamforming

Detecting objects in front of a PMUT is one thing, but scanning a 3D volume and achieving real-time operational capabilities required an entirely new level of sophistication.

Enter researchers with backgrounds from acoustics and array signal processing from the Nordic research ecosystem -University of Oslo (UiO), Technical University of Denmark (DTU), and SINTEF. These experts brought their deep knowledge of acoustic arrays and ultrasonic imaging to the project and ultimately provided the missing key: software beamforming.

In simple terms, beamforming allows energy to be sent or received from a specific direction. Cupping your hand around your ear to better hear a sound coming from one direction is a rudimentary yet effective form of beamforming.

Historically, beamforming was achieved mechanically, similarly to how modern LiDARs operate. Radars used rotating antennas, radio telescopes physically rotated to scan the sky, and medical ultrasound probes used tiny motors to steer an ultrasonic element.

The advent of digital signal processing made it possible to beamform without moving parts, through sophisticated manipulation of the signals received by each element in the array. Modern medical ultrasound systems exploit recent advances in hardware performance and signal processing, making software beamforming both convenient and effective for real-time applications.

The **University of Oslo** (UiO) is internationally recognized for its pioneering work in array signal processing, particularly in adaptive beamforming. UiO also contributed to the Center for Innovation Ultrasound Solutions (CIUS), a Center for Research based innovation funded by the Research Council of Norway,

SINTEF is an independent research organization founded in 1950, based in Norway. It includes the Micro and Nanotechnology Laboratory (MiNaLab).

The **Technical University of Denmark** (DTU) is a recognized internationally as a leading university in the technical and natural sciences.

The realization of ADAR

Following these innovations in miniaturization and signal processing, the foundation was laid to make 3D ultrasonic sensing in air a reality. Worldwide, there are very few groups that are both able to fabricate high quality PMUTs and do cutting edge array signal processing.

Seeing the potential in PMUT technology, SINTEF used the COVID19 period to demonstrate how the technology can be used for object tracking.

These demonstrations were so successful that in 2022, Sonair was founded. Sonair brings experts from various fields together, including leading researchers in PMUT technology, ultrasound, physics, software engineering, and medical imaging. The Sonair team secured exclusive global rights to SINTEF's PMUT technology for air applications and set out to design the first array for 3D ultrasonic sensing in air.

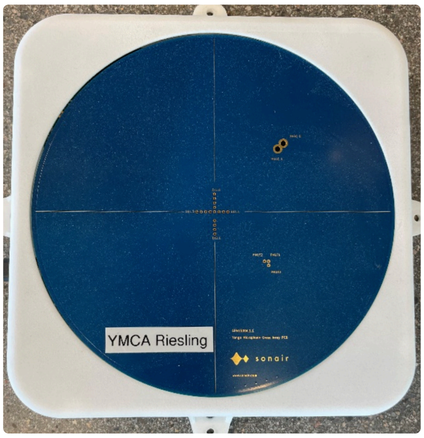


Image 4 Sonair's first prototype sensor "Yango"

Simultaneously, researchers tackled the challenge of implementing cutting-edge beamforming techniques, typically found only in high-end medical ultrasound scanners, within a lightweight, portable computing device. This required the development of novel beamforming algorithms, combined with in-depth knowledge of wave propagation and acoustics in air, that cuts the computational requirements to run the processing in real-time.

18 months later, the prototype was ready.

Sonair's product roll-out

Image 5 Sonair's evaluation kit, ready for customer testing

In May 2024, Sonair announced the release of its first evaluation kit, containing a miniaturized 3D ultrasonic sensor that provides autonomous machines with omnidirectional depth sensing. This delivers safe object detection, miniaturization, cost efficiency, and low power consumption compared to other methods for recording 3D information.

Sonair's sensor can monitor a hemisphere (a solid angle of 180° x 180°) with a range of up to 5 meters.

Weighing less than 250 grams, Sonair detects objects larger than 3 cm. All of this is achieved in a compact form factor of 9 x 9 x 2.5 cm in the evaluation kit with a power consumption of less than 5 watts.

Unlike the prevailing electromagnetic wave solutions (LiDAR and cameras), Sonair's ADAR demonstrates robust performance in challenging environments such as dust and varying light conditions, resulting in reliable and accurate 3D depth sensing.

As a result, autonomous mobile robots go from a narrow in-plane view (with 2D LiDAR) to an all-around view with Sonair. This increases the safety zone and enables human interaction. Participants in Sonair's Early Access Program tested and evaluated the development version of the 3D ultrasonic sensor. Testers helped to define product requirements across various industries and applications by relaying test results back to Sonair's research team.

In June 2024, Sonair made its global debut at the Sensors Converge conference in Santa Clara, where it won the Best of Sensors 2024 Award in the category of Automotive and Autonomous Systems.

The company plans to launch its first commercial product in 2025, with safety-certifiable hardware (SIL2 / Pl d according to IEC 61508 / ISO 13849).

Product specifications

Weight	<100 g
Range	0-5 m
Range precision	2 cm
Angular precision	2° (center) - 10° (edge)
Minimum detection capability	⌀30 mm cylinder up to 3 m ⌀70 mm cylinder up to 7 m
Output	Protective zone status (OSSD), 3D point cloud (Ethernet)
Ultrasonic frequency	70-85 kHz
Power consumption	Max 5 W (without output load)
Supply voltage	24 V DC (18 V to 28 V DC) (SELV/PELV)
Ingress protection (IP)	IP54
Temperature	-10 to +50 Celcius
Field of view (FoV)	180 x 180 degrees
Frame rate	20 Hz

Growing demand for autonomous systems

Why ADAR and why now? The world is increasingly driven by automation, and the demand for autonomous systems has reached unprecedented levels. From warehouse floors to airports, these systems are becoming integral to a wide range of industries. The push towards automation is not just a matter of convenience; it is the only viable response to the convergence of technological advancements and global economic shifts.

McKinsey estimates that automation will account for 25 percent of industrial companies' capital spending over the five next years.

The intersection of multiple cutting-edge technologies including machine learning (ML) and artificial intelligence (AI), enable computers to adapt to their environments with minimal human intervention. Simultaneously, innovations in sensor technology are empowering robots to perceive their surroundings more accurately and reliably. Robots interacting with humans or other robots have the potential to become a USD 375bn+ market by 2030, and all robots require sensors.

A prime example of this global trend is the race to develop fully autonomous vehicles. Companies like Waymo use AI to deliver the long-awaited promise of a fully automated taxi service. Today, they provide services in Los Angeles, San Francisco, and Phoenix, demonstrating the potential of AI-driven transportation. Fully autonomous systems are no longer confined to the realm of science fiction; they are here and increasingly becoming part of our daily life.

The demand for autonomous systems is also driven by economic and geopolitical forces. Labor shortages are spurring companies to invest heavily in automation. Tech giant Amazon, for instance, has deployed over half a million robots worldwide since 2012. Analysts estimate that over the past decade, Amazon's total investment in automation-related technology is estimated at $10 to $20 billion.

Recent geopolitical conflicts and global pandemics have highlighted the importance of resilient supply chains. Autonomous systems that can operate around the clock with minimal dependency on human labor, are critical to achieving this goal.

As these systems become more prevalent, the need for reliability and safety has never been greater. Machines are increasingly sharing both work and leisure spaces with humans.

Case study: Sonair’s Early Access Program

More than 20 companies explored Sonair’s ADAR technology, which is integrated into the company’s 3D ultrasonic sensor. These pioneers in the world of ADAR include AMR manufacturers, automotive makers, and technology vendors within the cleaning and health industries.

Sonair also worked with a few distributors and potential partners to explore indirect channels to the market.

The testers provided Sonair with exactly the type of actionable feedback that will shape the company's future

product development and go-to-market strategies. Their validation of how the company understand their challenges helps Sonair build solutions that solve the real-world pain points of AMR manufacturers.

What some of them said:

“This can be pretty disruptive for the robotics market.”
A major multinational electrical engineering corporation and a frontrunner in autonomous robotics

“The team is quite happy with how user-friendly the sensor is, [it is] plug-and-play.”
A North American manufacturer of agricultural robotics

"It performs well with [initial] tests, setting a monitoring zone with the lower boundary above the floor."
A top 5 global AMR manufacturer

Why do I need 3D?

You might wonder why 3D ultrasonic sensing is necessary when conventional ultrasonic range sensors have been around for over 30 years and are extremely cheap. There are several compelling reasons why Sonair's 3D ultrasonic sensing technology outperforms conventional ultrasonic range sensing technologies.

Firstly, traditional ultrasonic range sensors suffer from a form of "tunnel vision." They typically provide a narrow field of view, ranging from 10° to 45°, that limits their ability to detect objects outside that narrow cone. Secondly, these sensors have a single element, meaning they cannot focus their energy on a specific region of space. This limitation not only restricts them to tracking just one object at a time but also makes them susceptible to false readings caused by spurious echoes and background noise. Finally, without the ability to steer the beam, echoes coming from reflective surfaces are simply undetectable, unless they arrive from very specific angles.

Sonair's 3D ultrasonic technology addresses all these limitations. With a wide field of view covering 180° x 180°, a 16-element fully steerable array, ADAR offers unparalleled detection capabilities across a broader range of environments, for precise object tracking, even in complex and cluttered spaces.

Conclusion

Sonair's 3D ultrasonic sensor technology transforms how autonomous systems perceive and interact with their surroundings. Integrating 3D ultrasonic sensing into robotics and autonomous platforms is the logical next step to overcoming the limitations
of vision-only systems -enabling robot builders to achieve a level of reliability and safety that has never been possible before.

As the demand for autonomous solutions accelerates across industries, from logistics to transportation, the stakes have never been higher. Autonomous systems are no longer confined to controlled environments; they are entering our roads, factories, and homes. In these unpredictable settings, the ability to detect and respond to obstacles in real-time is paramount. ADAR provides this capability, enabling machines to operate with the precision and awareness needed to navigate complex real-world environments.

Offering 3D sensing capabilities that set new benchmarks in safety, accuracy, and adaptability, Sonair's technology doesn't just push the boundaries of what's possible; it will establish new industry norms, influence future safety standards and regulatory frameworks.

Sonair's technology is the future for industries seeking to deploy safe, reliable, and capable autonomous machines. With the potential to transform a wide range of applications, Sonair is poised to lead the next wave of innovation in autonomous technology, driving the industry towards a new era of multimodal sensing.

ADAR is a scalable, versatile technology with the power to change how machines and humans coexist seamlessly, efficiently, and, most importantly, safely.

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Author biography

Alfonso Rodríguez-Molares has held a PhD in Signal Processing since 2011, specializing in advanced ultrasound beamforming. A former academic at the Department of Circulation and Medical Imaging at the Norwegian University of Science and Technology (NTNU), he now applies his expertise in signal processing and machine learning to product development as a freelance innovator. He has published over 25 peer-reviewed articles, amassing 1,545 citations to date, and created the Ultrasound Toolbox (USTB)—an open-source platform widely embraced by the ultrasound research community.

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