Narrative Review Article

Artificial-Intelligence (AI) Enhanced Sonar Technologies and Emerging LiDAR Applications in Body Composition and Diagnostics

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ABSTRACT

This paper explores the integration of Sonar and LiDAR technologies in body composition imaging and biomedical applications. Sonar, primarily used in ultrasound and elastography, offers non-invasive, radiation-free imaging and therapeutic capabilities, including emerging uses in cell manipulation and tissue engineering. LiDAR, traditionally used in environmental mapping, is now being adapted for medical imaging through surface mapping, morphological analysis, and radiation-free 3D scanning. The synergy between these sensory technologies and artificial intelligence, particularly convolutional neural networks, enhances diagnostic precision, patient monitoring, and procedural guidance. This review highlights the strengths, limitations, and emerging innovations of Sonar and LiDAR in advancing non-invasive diagnostics and personalized medicine.

Keywords: LiDAR; Sonar; body composition; medical imaging; obesity; body mass index; artificial intelligence; morphological analysis

INTRODUCTION

Human intelligence is marked by its remarkable ability to think creatively, express emotions, learn from experience, and make nuanced decisions. In contrast, Artificial Intelligence (AI) seeks to replicate aspects of human cognition through data-driven learning and pattern recognition (1). AI systems learn by analyzing large datasets to identify patterns and relationships, similar to how humans learn from experience (2). Depending on the intended application, AI models are trained using different types of data (numerical or categorical) and employ tailored algorithms to optimize performance. These pattern recognition capabilities are particularly valuable in medical imaging, where AI can enhance the interpretation of complex visual data and improve diagnostic accuracy.

One specialized application of AI involves integrating sensory technologies like LiDAR and Sonar for mapping and digital interfaces (Figure 1 and Table 1). LiDAR (Light Detection and Ranging) uses laser pulses to measure distances by calculating the time it takes for light to reflect off surfaces, producing high-resolution topographical maps and 3D models (3). LiDAR is increasingly used in body composition

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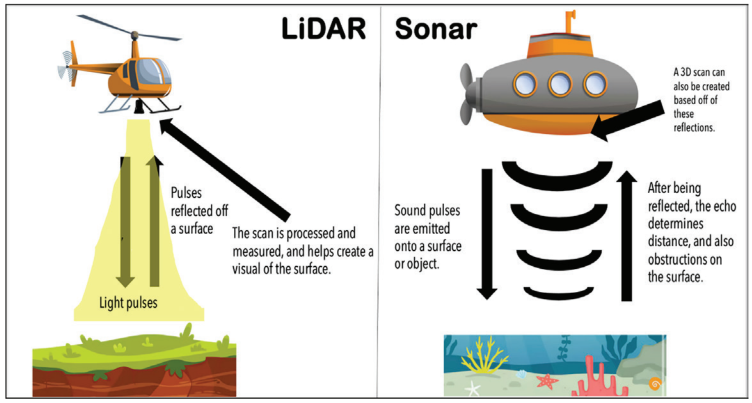

Figure 1. LiDAR and Sonar diagram. LiDAR (Light Detection and Ranging) uses laser light to measure distances by calculating the time it takes for the light to reflect off surfaces, creating detailed 3D maps. Sonar (Sound Navigation and Ranging) uses sound waves to detect and locate objects by measuring how long it takes for the sound to bounce back after hitting a surface.

Table 1. Differences between Sonar and LiDAR technologies

Technology name	Sonar: Sound Navigation and Ranging	LiDAR: Light Detection and Ranging
Strengths	• Already prominent in the medical imaging field. • Acoustic or sound vibrations are safer than normalized X-rays.	• LiDAR can create a highly detailed 3D model of the body that can help clinicians in diagnosing/noticing faults. • Radiation-free imaging using non-ionizing radiation lasers, safe for repeated clinical use • LiDAR has a high accuracy and is widely used in various mapping-related fields.
Weaknesses	• Sonar/Ultrasound machines are fairly expensive, ranging from $20,000 to $200,000 per machine. • Sound vibrations do not travel well through bones, posing a challenge to scans which require more depth.	• Medical-grade LiDAR devices can cost an astonishing $120,000 to $300,000.
Body Composition Insights	• Examples of implementation of Sonar into body composition and studies include elastography, tissue engineering, and cell manipulation. • Sonar helps in elastography by sending vibrations into the body, measuring the velocity and distance of them, and then determining tissue stiffness and other organ obstructions. • Sonar aids in tissue engineering by stimulating tissue with sound vibrations, which eventually lead to sped up growth. • Sonar can be utilized in cell manipulation to acoustically shift or alter the figure and presence of a cell. • Overall, Sonar provides real-time imaging of internal structures using acoustic waves, with tissue characteristics such as stiffness inferred through elastography rather than direct visualization of cellular detail.	• Examples of implementation of LiDAR into body composition imaging and studies include surface mapping for image fusion, body composition and morphological imaging, and radiation-free 3D scanning • LiDAR helps in surface mapping for image fusion by providing instant information to clinicians after scanning an area, adjusting a patient's position in a procedural setting, and improving visualization by creating an accurate model that serves in efficiency. • LiDAR aids in body composition and morphological imaging by predicting body composition based on an exterior scan and some crucial data on the patient such as height, weight, and age. 3D body surface scanning is another technique that uses LiDAR technologies to calculate the dimensions of a patient. • LiDAR can be utilized in radiation-free 3D scanning, monitoring any patient activity by tracking movement, all without requiring wearable devices. It provides valuable information for analyzing and diagnosing various conditions and faults. • Overall, LiDAR primarily captures external contours, and internal composition is inferred through predictive modeling rather than direct imaging.

imaging, enabling radiation-free surface mapping and morphological analysis (4, 5). Sonar (Sound Navigation and Ranging) operates similarly but uses sound waves instead of light. It emits acoustic pulses that reflect off objects, allowing for precise distance and shape measurements (6). Sonar has well-established applications in medical imaging, such as ultrasound elastography for tissue characterization (7), and promising emerging uses in therapeutic domains like cell manipulation and tissue engineering (8). Acoustic stimulation alters the mechanical environment of cells, promoting mechanotransduction pathways that influence cell differentiation and proliferation. These vibrations can modulate scaffold stiffness and guide cell alignment, enhancing tissue formation.

The integration of AI with sensory technologies like Sonar and LiDAR is transforming fields from environmental mapping to biomedical imaging. As these systems continue to evolve, they offer increasingly sophisticated insights that mirror and sometimes surpass human capabilities. The objective of this article is to review the integration of Sonar and LiDAR technologies with artificial intelligence in body composition imaging and biomedical diagnostics, highlighting their current applications, emerging innovations, and future potential in non-invasive healthcare.

BODY COMPOSITION IMAGING: BRIDGING DIAGNOSTIC GAPS

Body composition imaging is a diagnostic technique used to assess the distribution and quantity of key physiological components: such as fat, muscle, tissues, and bone within the human body. This evaluation is typically conducted using advanced imaging modalities, including Dual-Energy X-ray Absorptiometry (DEXA), computed tomography (CT), and magnetic resonance imaging (MRI), each offering unique insights into structural and compositional health.

Sonar technology has long played a pivotal role in medical imaging, with ultrasound being its most prominent application. Ultrasound utilizes high-frequency sound waves to generate real-time visualizations of internal body structures (e.g., organs, tissues, and blood flow) and is both non-invasive and radiation-free, making it a safe and effective method for diagnostic imaging across a wide range of clinical settings (6).

While ultrasound has revolutionized visual screening in clinical practice, Sonar-based technologies continue to evolve beyond traditional imaging. Their applications now extend into therapeutic diagnostics, with notable advancements in using acoustic energy for cell manipulation and tissue engineering processes. These developments highlight Sonar's expanding role in both assessing and influencing biological structures at increasingly precise levels.

Elastography is an advanced ultrasound imaging technique that evaluates tissue stiffness (elasticity) by transmitting sound waves into specific tissues and analyzing their mechanical response. Beyond quantitatively measuring elasticity, elastography serves as a powerful diagnostic tool for identifying conditions such as liver fibrosis and thyroid abnormalities, and for distinguishing benign from malignant tumors (7). Founded on Sonar technology, elastography exemplifies how acoustic imaging continues to shape the future of non-invasive diagnostics and improve clinical decision-making.

ADVANCED BIOMEDICAL APPLICATIONS IN CELL MANIPULATION AND TISSUE ENGINEERING

Cell manipulation is another emerging frontier in biomedical innovation. It involves altering cells, such as their location, shape, or internal components, to achieve specific outcomes in research, diagnostics, or therapeutics. Traditionally, cell manipulation is executed using approaches like optical tweezers, microfluidic devices, magnetic forces, and electroporation, each offering precise control over cellular behavior (9). These techniques allow researchers to sort, move, or modify cells in vitro, and have become essential tools in fields ranging from oncology to immunology. As this field advances, it promises to unlock new possibilities in tissue engineering, regenerative medicine, and targeted treatment strategies.

Tissue engineering is a branch of biomedical engineering dedicated to cultivating functional tissues in laboratory settings to repair or replace damaged organs and biological structures. This process relies on a triad of key components: cells, scaffolds, and growth factors. Typically, primary cells are harvested from a patient, then isolated and expanded *in vitro* to promote proliferation. The cells are then seeded onto scaffolds, which serve as a temporary support structure for proper growth and tissue formation, mimicking the architecture of native extracellular matrix (10). Scaffolds can be fabricated from various biomaterials (natural or synthetic) chosen to suit the cell type and desired tissue function. Growth factors, which are protein-based signaling molecules, are introduced to stimulate cellular growth, differentiation, and functional development – all playing a critical role in orchestrating tissue regeneration (10).

As research progresses, new techniques are emerging to integrate Sonar technology into cell manipulation and tissue engineering. For instance, principles from elastography – where high-frequency ultrasound vibrations correlate with tissue density – are being adapted to guide cellular behavior and scaffold interactions in engineered tissues (8). Techniques involving both high- and low-frequency acoustic waves, delivered via ultrasound transducers or mechanical actuators, are under investigation for their potential to influence cell positioning, differentiation, and integration within synthetic environments (8). This acoustic stimulation can create dynamic mechanical cues in cell culture systems, effectively a "remote control" for cell assembly and fate without physical contact.

Other innovative applications of Sonar technology are rapidly advancing the field of cell manipulation. Notable advancements include acoustofluidics, acoustic tweezers, sonogenetics, and the use of microbubbles. *Acoustofluidics* involves microfluidic devices that utilize acoustic vibrations to separate or manipulate cells in a contact-free manner, significantly reducing the risk of cellular damage compared to traditional mechanical methods. This technique enables the isolation of rare cell populations (e.g. circulating tumor cells), offering promising insights into cancer diagnostics and metastasis research (9). Furthermore, *acoustic tweezers* utilize highly focused sound waves to move, trap, and even deform individual cells with great precision. This contactless control makes them a powerful tool for studying cellular biomechanics and interactions, as well as constructing organized cell cultures and engineered tissues (11). In addition, *sonogenetics* has emerged as a novel non-invasive technique that uses focused ultrasound to remotely stimulate or modulate the activity of genetically sensitized cells (analogous to optogenetics but with sound). Early demonstrations of sonogenetics showed that low-intensity ultrasound can activate specific neurons in model organisms without harming surrounding tissue (12). Despite significant progress, challenges remain in certain areas of acoustic imaging, particularly in visualizing blood vessels with ultrasound alone. To address this, *microbubbles* (gas-filled microspheres roughly the size of a red blood cell) are injected as contrast agents to enhance vascular imaging during ultrasonography. These microbubbles act as highly efficient reflectors of sound, dramatically improving the contrast and quality of ultrasound images of blood flow and perfusion (13). By resonating in the ultrasound beam, microbubbles help overcome limitations in seeing small or deep vessels, thus extending Sonar's diagnostic reach in cardiology, radiology, and beyond.

NAVIGATING LIDAR'S ROLE IN BIOMEDICAL IMAGING

While Sonar-based technologies are being adapted for cellular and subcellular applications, LiDAR systems are also being explored for their potential in body composition imaging and other medical uses. However, certain LiDAR systems (especially older or industrial models) may emit ultraviolet (UV) or high-energy laser beams to scan environments, raising safety concerns when applied to human subjects. Exposure to intense UV or high-frequency laser radiation can be harmful – it may cause skin damage or even temporary/permanent blindness if proper precautions are not taken (14). Fortunately, LiDAR systems designed for medical use typically employ non-ionizing wavelengths, which do not carry these risks, making them safer for integration into clinical imaging workflows. In practice, medical LiDAR devices most commonly use near-infrared lasers (usually in the ~800–905 nm range) or visible-spectrum green lasers (around 532 nm). These wavelengths are generally considered eye-safe at the power levels used and are compatible with existing imaging technologies (3). By avoiding ionizing radiation (such as X-rays or UV), medical LiDAR offers a radiation-free scanning modality that can be used repeatedly without harm to patients or operators. For instance, the Swift Ray 1 system, developed by Swift Medical, is a CE (Conformité Européenne or European Conformity)-marked hyperspectral imaging device used in clinical dermatology and wound assessment (15). It integrates thermal and bacterial imaging capabilities into a compact, smartphone-compatible format, enabling clinicians to visualize inflammation, bacterial colonization, and tissue perfusion in real time. Its portability and compatibility with electronic health records make it suitable for use in hospitals, clinics, and home care settings.

Similarly, the Artec Leo scanner is a wireless, AI-powered 3D imaging device capable of capturing high-resolution surface data (16). While primarily used in industrial and research contexts, it has been explored for medical applications such as body morphology assessment and wound documentation. However, unlike Swift Ray, Artec Leo is not currently CE-marked or FDA-approved specifically for clinical use, and its integration into healthcare workflows remains investigational.

The systematic implementation of LiDAR into medical imaging has enabled advancements in surface mapping for image fusion, body composition and morphology assessment, and radiation-free 3D scanning. Surface mapping involves using laser pulses to measure and reconstruct detailed topographies of anatomical regions. In clinical contexts, this technique supports precise patient positioning, real-time procedural guidance, and enhanced visualization during interventions. For example, LiDAR-based surface imaging can track a patient's body contours and posture, allowing clinicians to achieve optimal alignment and reproducibility in imaging or radiation therapy (minimizing variability in outcomes). Real-time guidance during procedures can leverage LiDAR's ability to provide instantaneous spatial data, aiding in navigation and avoidance of obstacles (such as surgical tools or anatomy) during operations. Improved visualization comes from generating highly detailed 3D representations of patient anatomy; when these are integrated with artificial intelligence (e.g., convolutional neural networks for image analysis), LiDAR-enhanced imaging can automatically identify anatomical features or flag potential abnormalities, increasing diagnostic efficiency and precision. This synergy between LiDAR and AI contributes to greater accuracy in medical imaging and diagnostics by combining rich spatial information with pattern recognition algorithms.

LIDAR IN BODY COMPOSITION AND MORPHOLOGICAL IMAGING

Body composition and morphological imaging are essential for assessing the distribution of tissues such as muscle, fat, and bone in the body. While LiDAR is predominantly applied to evaluate external surface contours of objects or the human body, its data can sometimes be leveraged to indirectly estimate internal body composition and fat percentage with notable accuracy (4). Although current clinical applications of LiDAR in this domain are limited, ongoing research is rapidly expanding its potential. Emerging techniques include predictive modeling of body composition using 3D scans and 3D body surface scanning. In predictive modeling, high-resolution LiDAR-derived surface data are combined with demographic and biometric inputs (such as a person's height, weight, age, and BMI) to estimate internal composition. Using machine learning algorithms – particularly CNN-based models – on large datasets of individuals, researchers have achieved remarkably accurate predictions of total and regional adiposity from external body shape information (17). *3D body surface scanning* is a non-invasive technique that captures detailed body measurements and generates a digital avatar (point cloud) of the patient's body. When multiple scans are aggregated, they form a dense collection of spatial data points that precisely map the dimensions and morphology of the body's exterior. This technique offers a radiation-free alternative to traditional imaging modalities like DEXA, and has shown promise for clinical, fitness, and research applications (5, 17). For instance, recent studies have demonstrated that 3D optical scans of the body can predict body fat and muscle mass comparably to gold-standard methods, providing an attractive option for large-scale or frequent monitoring without exposure to radiation (17).

RELATED OPTICAL TECHNOLOGIES

Although structured-light and infrared systems are not strictly LiDAR, they share similar principles in surface mapping and are increasingly relevant for non-invasive body composition analysis. Building on these similarities, commercial 3D scanning devices such as Styku and Fit3D use these technologies to calculate metrics like body volume and fat percentage, offering radiation-free alternatives for clinical and wellness applications. These devices (e.g. Styku and Fit3D) utilize infrared depth sensors and structured light to construct detailed 3D models of the body's surface; these models are then analyzed to determine anthropometric measurements and estimate tissue composition (18). The output can include calculations of body fat percentage, regional muscle distribution, and other composition indices. Validation studies have found that high-quality 3D body scanners are capable of estimating body volume and fat with reasonable accuracy compared to traditional methods, with test-retest reliability typically within a few percent (4). The advantage of these systems is that they are quick, non-invasive, and easily repeatable – making them useful in settings like fitness centers, weight loss clinics, and telehealth. Radiation-free 3D scanning encompasses a broad range of technologies, but key areas where LiDAR-style integration is particularly impactful include medical diagnostics, patient monitoring, and non-invasive imaging. For example, LiDAR sensors can be used to monitor a patient's activity and mobility by passively tracking their movements in an environment, all without requiring any wearable devices – offering a unobtrusive method for gait analysis and fall prevention in elderly care (19). In wound care, handheld LiDAR cameras have been applied to rapidly measure wound dimensions and aid in assessing healing, providing phenotypical insights that inform treatment decisions (20). These applications demonstrate how LiDAR can extend beyond static imaging into dynamic health monitoring and personalized care.

LiDAR performs imaging scans using near-infrared or green laser light, both of which are non-ionizing and safe for human exposure. These systems emit laser pulses onto a surface and record the reflected signals to capture the precise dimensions and contours of the scanned environment or body. The resulting data are then processed into a digital 3D representation, enabling clinicians to visualize and analyze anatomical features with a high degree of precision (3). By calibrating the scale of the point cloud or 3D model, measurements such as lengths, areas, and volumes of body regions can be computed automatically – tasks that would be tedious or prone to error if done manually. This combination of speed, safety, and detail underlies LiDAR's appeal in medicine.

As demonstrated by its diverse applications, LiDAR is becoming a highly practical tool in the medical field. Its ability to enhance diagnostic accuracy, streamline workflows, and reduce patient risk underscores its growing significance in modern healthcare. By improving efficiency and minimizing stress for both patients and providers, LiDAR-based imaging technologies have the potential to transform clinical practice in the coming years.

LIMITATIONS

Despite their promise, Sonar and LiDAR technologies face several practical and technical challenges that limit widespread adoption. Beyond high equipment costs, implementation requires specialized operator training to ensure accurate image acquisition and interpretation. Both modalities generate large volumes of data, creating significant demands for storage, processing power, and secure transmission—particularly when integrated with AI algorithms. Compatibility with existing healthcare IT systems and electronic health records remains a hurdle, as does the need for standardized protocols to validate accuracy across diverse patient populations. For LiDAR, limited penetration depth restricts its use to surface imaging, while Sonar struggles with acoustic shadowing and reduced resolution in obese or calcified tissues. Additionally, regulatory approval pathways for emerging applications are lengthy, and reimbursement models are not yet well established. Addressing these limitations will be critical for translating these technologies from research to routine clinical practice.

CONCLUSION

The convergence of Sonar and LiDAR technologies with AI is reshaping the landscape of medical imaging and diagnostics. Sonar's acoustic capabilities have evolved beyond traditional ultrasound to enable elastography, cell manipulation, and even tissue engineering applications. Meanwhile, LiDAR's precision in surface mapping and 3D modeling offers a radiation-free alternative for body composition analysis, patient monitoring, and telemedicine. Despite challenges such as equipment cost, data processing complexity, and certain imaging limitations, both technologies demonstrate immense potential in enhancing clinical workflows and patient outcomes. As medicine continues to embrace innovation, the development and refinement of these sensory tools – empowered by AI-driven analytics – will be pivotal in driving forward personalized, efficient, and non-invasive healthcare solutions.

Future research should refine AI algorithms for real-time interpretation of Sonar and LiDAR data, while expanding clinical validation for LiDAR-based body composition and Sonar-driven elastography and tissue engineering. Combining Sonar's ability to penetrate tissue with LiDAR's high resolution surface imaging could enable early detection of irregularities in the body and disease markers. Thus, efforts to reduce hardware costs, integrate these technologies with telehealth and wearable platforms, and establish regulatory and reimbursement pathways will be essential for widespread adoption.

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AUTHOR CONTRIBUTIONS

AA conceptualized and wrote the first draft, including drawing the figure and table. AVM edited the manuscript and performed content verification with references. GS supervised and performed language, grammar and formatting edits. All authors edited and approved the final draft.

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