

# Contactless ultrasound imaging for pediatric forearm fracture detection

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*Abstract: Pediatric forearm fractures are common, and while X-ray imaging is the standard for diagnosis, minimizing radiation exposure is critical. Ultrasound offers a non-invasive, radiation-free alternative, but its reliability depends on operator skill. This study presents a contactless ultrasound imaging approach for pediatric forearm fracture detection, in which the forearm is submerged in water while the ultrasound probe remains outside a purpose-built water tank. Manual imaging of phantoms and a human forearm demonstrates the feasibility of capturing high-quality images without direct contact. This approach improves patient comfort and safety and establishes a foundation for future robot-assisted automation and clinical validation.*

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## I. Introduction

Pediatric forearm fractures are common due to children's high activity levels. Although X-ray imaging remains the clinical standard for fracture diagnosis, reducing radiation exposure is essential in accordance with the ALARA (As Low As Reasonably Achievable) principle [1]. Ultrasound offers a non-invasive, radiation-free alternative; however, its accuracy depends heavily on the operator's expertise. Robotic assistance can help overcome this limitation by ensuring consistent probe positioning and image quality, as demonstrated in the ROPCA project for finger-joint scanning [2]. In conventional ultrasound imaging, direct probe contact with a potentially fractured forearm may cause discomfort for pediatric patients and degrade image quality. A contactless scanning approach could reduce pain and improve patient tolerance, thereby supporting more reliable imaging outcomes.

Previous work has demonstrated the feasibility of underwater ultrasound imaging using robotic systems in which both the probe and the affected limb are fully submerged [3]. Our own results, presented at the German Robotics Conference (GRC) 2025, further confirmed that water enables effective acoustic coupling for contactless sonography. However, submerging the probe and robotic components also introduces practical limitations.

To address these challenges, we are developing a robot-assisted contactless ultrasound system for pediatric forearm fracture detection. This study evaluates a manual approach in which the probe is pressed against the outer wall of a water tank while the forearm is submerged inside, as shown in Fig. 1. This configuration enables fully contactless imaging without immersing the probe and lays the foundation for future robotic automation.

## II. Material and methods

This study used two pediatric forearm phantoms of different sizes and the forearm of an adult test subject. Each phantom contains two 3D-printed bones representing the radius and ulna of the forearm, as shown in Fig. 2. The larger phantom, measuring 21.5 cm in length and approximately 20 cm in circumference, models the forearm of a 10–12-year-old child and includes a simulated ulnar fracture. The smaller phantom, measuring 13 cm in length and about 15 cm in circumference, represents a 2–3-year-old child and features intact bones.

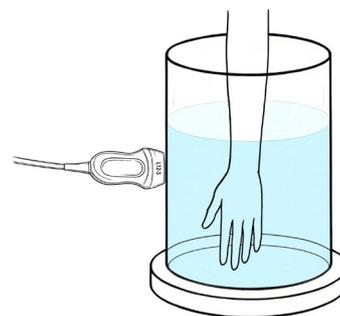


Figure 1: Concept diagram of contactless ultrasound imaging for pediatric fracture detection.

### II.II. Design of Water Tank

To enable contactless imaging, we employed a cylindrical water tank designed so that the probe can be pressed against its outer wall rather than submerged. The tank is built from a 400 mm-long PolyMethyl MethAcrylate (PMMA) pipe with a 200 mm outer diameter, selected to accommodate typical pediatric forearm dimensions. Its 3 mm wall thickness provides a short acoustic path between the probe and the water while maintaining structural stability. The base plate is 3D-printed from water-resistant ABS, and the

PMMA pipe is bonded to it using silicone adhesive to ensure a secure, watertight seal.

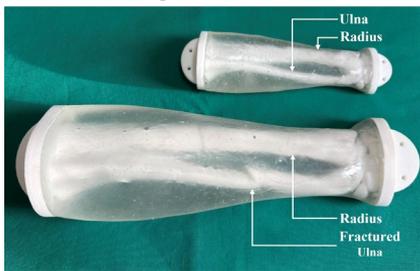


Figure 2: Pediatric forearm phantoms with 3D-printed radius and ulna, with the larger phantom simulating an ulnar fracture.

Ultrasound propagation depends on the acoustic impedance and density of the media it traverses. The longitudinal sound velocity is approximately 1480 m/s in water, 1540 m/s in soft tissue, and about 4080 m/s in bone, making ultrasound well-suited for fracture detection. In our previous contactless approach, only the acoustic properties of water were relevant because the probe was fully submerged. In the proposed method, however, ultrasound must also pass through the PMMA tank wall, requiring consideration of PMMA's acoustic characteristics. PMMA has a sound velocity of 2750 m/s. It has an acoustic impedance of 3.26 MRayls, compared to 1.49 MRayls for water, leading to partial wave reflections at the PMMA–water interface [4]. Consequently, the tank's material and geometry are essential for ensuring efficient ultrasound transmission.

## II.II. Ultrasound Image Acquisition

Ultrasound imaging was performed using a Philips EPIQ system with a linear L12-3 probe operating at 3–12 MHz and an imaging depth of 7 cm. The tank was filled with 8.8 liters of room-temperature water for vertical forearm submersion. Ultrasound gel was applied to the probe to enhance coupling between the probe and the tank, and images were acquired by pressing the probe against the tank wall for fully contactless scanning. After the pediatric forearm phantom was fully submerged, the ultrasound probe was moved around the tank to capture images from multiple angles. Throughout imaging, the probe remained pressed against the tank wall and never contacted the phantom. The same protocol was applied to an adult forearm.

## III. Results and discussion

Our previous work, presented at GRC 2025, demonstrated contactless underwater ultrasound imaging capable of visualizing fractures without degrading image quality. However, the requirement for full probe submersion can reduce probe lifespan despite water-resistant protection, and submerging the robot introduces risks such as component corrosion and challenges in tank disinfection. Given the high frequency of pediatric fracture examinations, a contactless approach that keeps both the probe and robot outside the water is therefore preferable.

Fig. 3 shows the ultrasound images acquired using the proposed method. High-resolution images were obtained in both cases: Fig. 3a displays the radius of an adult forearm scanned through the outer tank wall, and Fig. 3b clearly

visualizes a simulated ulnar fracture in the phantom. Image quality remains comparable to that of our previous submerged-probe approach, confirming that the proposed method successfully images forearm bones.

Although water and PMMA differ in acoustic impedance and sound velocity, the selected wall thickness minimizes wave attenuation and energy loss while maintaining structural stability. The cylindrical shape of the tank helps manage wave propagation by dispersing unwanted reflections that could otherwise return directly to the transducer. No measurable ultrasound attenuation in water was observed. In this method, the forearm is positioned vertically rather than horizontally, which can reduce the pain during placement and improve patient comfort. To further stabilize the forearm during scanning, a height-adjustable fixture could be incorporated in future designs.

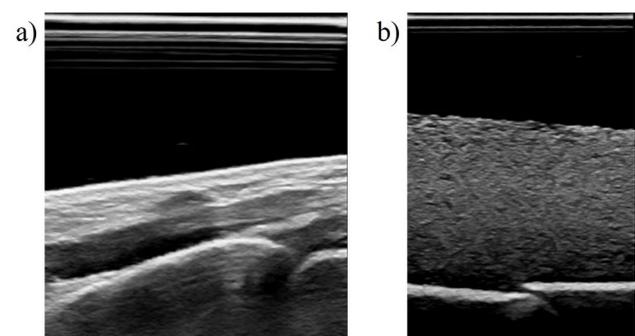


Figure 3: Ultrasound images acquired using the proposed contactless imaging method. a) Ultrasound image of the radius of the forearm of the test subject. b) Ultrasound image of the fractured ulna of the pediatric forearm phantom.

## IV. Conclusions

The proposed method enables contactless ultrasound imaging by submerging the forearm while keeping the probe and robot outside the tank. A purpose-built setup demonstrates feasibility and improved comfort, providing a basis for future robot-assisted automation and clinical validation.

### AUTHOR'S STATEMENT

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