Interactive Guidance for Self-Acquisition of Ultrasound Images by Hemophilic Patients

Dragan Ahmetovic
Dept. of Computer Science
Università degli studi di Milano
Milano, Italy
dragan.ahmetovic@unimi.it

Claudio Bettini
Dept. of Computer Science
Università degli Studi di Milano
Milano, Italy
claudio.bettini@unimi.it

Marco Colussi
Dept. of Computer Science
Università degli Studi di Milano
Milano, Italy
marco.colussi@unimi.it

Stefano Giacoia
Dept. of Computer Science
Università degli Studi di Milano
Milano, Italy
stefano.giacoia@studenti.unimi.it

Roberta Gualtierotti
Fondazione IRCCS Ca? Granda
Ospedale Maggiore Policlinico di Milano
Milano, Italy
Dept. of Pathophysiology and Transplantation
Università degli Studi di Milano
Milano, Italy
roberta.gualtierotti@unimi.it

Matteo Manzoni
Dept. of Computer Science
Università degli Studi di Milano
Milano, Italy
matteo.manzoni@unimi.it

Sergio Mascetti
Dept. of Computer Science
Università degli Studi di Milano
Milano, Italy
sergio.mascetti@unimi.it

Flora Peyvandi
Fondazione IRCCS Ca' Granda,
Ospedale Maggiore Policlinico di Milano
Milano, Italy
Dept. of Pathophysiology and Transplantation
Università degli Studi di Milano
Milano, Italy
flora.peyvandi@unimi.it

Abstract

Timely diagnosis of joint bleeds is crucial for preventing long-term damage in patients with hemophilia. However, access to specialized care and the operator-dependent nature of ultrasound imaging pose significant challenges for remote monitoring. We present GAJA (Guided self-Acquisition of Joint ultrAsound images), a mobile system that interactively guides patients during the acquisition of joint ultrasound images without requiring real-time supervision. The version of GAJA presented in this paper extends support beyond the knee to include elbow and ankle joints and integrates with the CADET platform, enabling clinicians to remotely assess the acquired images. In this demo, we showcase GAJA's real-time guidance interaction and its integration with remote clinical workflows.

MobileHCI '25 Adjunct, Sharm El-Sheikh, Egypt

ACM ISBN 979-8-4007-1970-7/25/09
https://doi.org/10.1145/3737821.3748527

CCS Concepts

• **Human-centered computing → Ubiquitous and mobile computing systems and tools**; • **Applied computing → Health informatics**; • **Computing methodologies →** *Computer vision.*

Keywords

AI assistance, interactions, hemophilia, ultrasound, telemedicine

ACM Reference Format:
Dragan Ahmetovic, Claudio Bettini, Marco Colussi, Stefano Giacoia, Roberta Gualtierotti, Matteo Manzoni, Sergio Mascetti, and Flora Peyvandi. 2025. Interactive Guidance for Self-Acquisition of Ultrasound Images by Hemophilic Patients. In *Adjunct Proceedings of the 27th International Conference on Mobile Human-Computer Interaction (MobileHCI '25 Adjunct), September 22–25, 2025, Sharm El-Sheikh, Egypt.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3737821.3748527

1 Introduction

People with hemophilia are at risk for joint bleeds that, if not detected and managed promptly, can progress to chronic diseases such as synovial hyperplasia, cartilage degeneration, and ultimately hemophilic arthropathy [11]. Ultrasound (US) has emerged as a standardized approach to asses various pathologies in hemophilic treatment [10].

Routine in-clinic evaluations may be impractical for patients who live far from specialized centers or when urgent care is required. In addition, healthcare centers are facing increasing burden due to resource limitations, making it difficult to accommodate frequent or emergency appointments. To address this gap in access and scalability, the University of Milan and the Policlinico di Milano developed a telemedicine system to allow joint assessment at home. In this system, patients are equipped with a tablet-connected portable ultrasound probe. When pain occurs or routine monitoring is necessary, patients (or caregivers) can perform a scan and directly send the resulting images to a remote diagnostic server, where healthcare providers can review them through a Computer-Aided Diagnosis system (CADET) [2].

A key challenge in this scenario is the variability in image quality that can be caused by the operator's lack of expertise. Prior efforts to address this challenge have taken two main directions: training patients to perform acquisitions independently after an initial learning phase [9], or offering real-time remote guidance from medical professionals during the scan [3]. However, these solutions are limited by their long-term effectiveness and scalability: patients may forget proper techniques over time [1], and real-time supervision places significant demands on clinical staff.

To solve these limitations, we introduced GAJA (Guided self-Acquisition of Joint ultrAsound images) [6], a novel system that automates real-time interaction during ultrasound acquisition. GAJA provides users with continuous, intelligent guidance throughout the scanning process, assisting them in capturing diagnostically useful images without requiring live supervision. This approach combines the strengths of prior methods by embedding a real-time, interactive guidance system directly into the ultrasound acquisition process. Rather than relying on live supervision from a medical professional, GAJA relies on machine learning to provide dynamic, on-screen instructions that respond to the user's actions. Patients are actively engaged in a step-by-step interaction loop, where the system offers clear visual and textual cues, and users adjust the probe accordingly. Additionally, by requiring patients to repeatedly follow guided procedures during each new scan, the system reinforces proper technique over time, helping mitigate skill decay.

In this demonstration, we showcase a new version of GAJA, which improves upon the initial prototype (presented in [6]) in several key aspects. The system is now more robust and supports additional joints beyond the knee, including the elbow and ankle, enabling comprehensive monitoring across all six commonly affected joints (right and left knees, elbows, and ankles). Furthermore, GAJA is now directly integrated with the CADET platform, allowing medical practitioners to remotely evaluate the acquired images. This integration streamlines the workflow, enabling targeted assessments while maintaining continuity of care. During the demo, we will showcase the end-to-end interaction between patient and system, illustrating how users are guided through the acquisition process, focusing on the interaction with the mobile system, and how practitioners manage and review examinations remotely. For an in-depth description of the implementation details of GAJA and CADET, we refer the reader to the original publications [2, 6].

2 Related Work

The use of portable ultrasound (US) systems has gained significant attention in recent years, particularly for enabling diagnostic procedures outside of traditional clinical environments such as emergency sites or patients' homes [7, 12, 13]. In the context of remote or self-operated imaging, the literature typically distinguishes three primary strategies.

The first strategy emphasizes patient education, aiming to equip individuals with the necessary skills to independently perform US scans [5, 9, 15]. Although this method promotes autonomy, it depends heavily on the patient's ability to retain and correctly apply scanning techniques over time. An alternative strategy involves real-time remote assistance, commonly referred to as teleguidance. In this setup, a healthcare provider supervises the scanning session by monitoring the live US feed [3], sometimes complemented by video from additional cameras [14]. With advances in network infrastructure, such as 5G connectivity, teleguidance is becoming increasingly feasible for real-world deployment [4]. Nevertheless, this approach imposes a significant time burden on medical staff, limiting its scalability [3, 14].

A recent study focusing on hemophilia care compared these two approaches in the context of self-administered joint imaging using portable US probes [1]. The authors observed that, despite initial training (several hours), patients' ability to produce diagnostic-quality images declined over time when working independently. In contrast, image quality remained high when sessions were conducted under teleguidance. However, other studies revealed that real-time involvement of practitioners is not sustainable at scale [6].

The third line of research investigates automated guidance systems, where an AI-driven interface assists the user during the scanning process. Prior work in this area typically involves external cameras mounted on the probe to track and direct positioning [8, 16]. As part of this research direction, our previously developed system, GAJA [6], proposed a camera-free automated guidance approach. The system relies exclusively on the ultrasound feed to interactively guide users during the acquisition of knee joint images, demonstrating the feasibility of supporting self-imaging without external hardware dependencies.

In this demo, we present an updated version of GAJA that addresses one of the main limitations of the original system: its restriction to knee joint support. The new version extends support to include elbow and ankle joints, using the same automate-guide-remind interaction paradigm to provide real time adaptive guidance during acquisition.

3 The GAJA System

This section presents the system architecture supporting remote ultrasound acquisition and diagnosis, highlighting the roles of the GAJA tablet application. We focus in particular on GAJA's interaction design, which guides patients through the acquisition process via real-time visual feedback, enabling patients to capture diagnostically useful images.

3.1 System Architecture

Figure 1 provides an overview of the architecture that supports the GAJA system. While GAJA is part of the broader PRACTICE

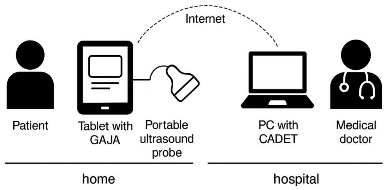


Figure 1: Architecture overview. The system has two main components: the mobile system @home, and the CAD system @hospital.

framework [2], the diagram presents a simplified view, highlighting only the components directly involved in GAJA's operation. The architecture of the system connects the caring environment of the patient to the hospital infrastructure through a telemedicine workflow. On the patient side, the user operates a portable ultrasound probe connected to a tablet running GAJA, which provides interactive guidance during image acquisition. These devices form the local interface for data collection. Once acquired, images and session metadata are transmitted to a server, which manages access control. In the hospital, clinicians review the performed examination through the CADET web application, make diagnostic decisions, and provide feedback on the evaluation. This architecture supports asynchronous collaboration, enabling patients to perform guided acquisitions independently while maintaining clinical oversight.

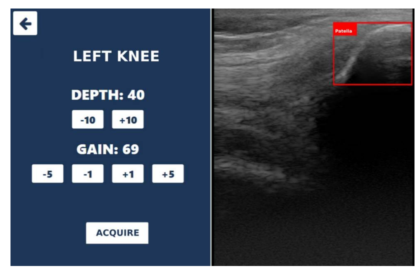
3.2 Interaction Design

Previous studies have shown that learning to self-acquire US images is challenging, and that patients tend to forget how to properly handle and position the probe over time. We hypothesize that this difficulty arises from the number and complexity of actions required for successful image acquisition. These include tasks such as correctly positioning and angling the probe, flexing the joint appropriately, applying gel, and configuring imaging parameters.

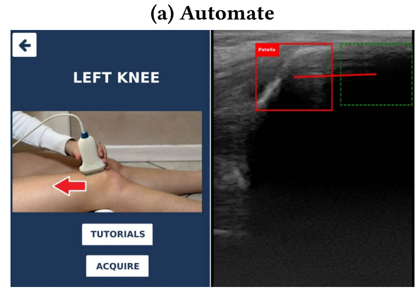
To address these challenges, GAJA adopts a collaborative interaction model involving both the medical practitioner and the patient. This model consists of two phases: a setup phase, in which the practitioner and patient collaborate in person to configure the system and ensure proper usage, and a self-acquisition phase, where the patient independently conducts the ultrasound scan by following the system's interactive guidance and prompts. In addition, during the self-acquisition phase, GAJA implements the automate–guide–remind design principle [6], to further mitigate the decline of patient skills over time.

3.2.1 Collaborative interaction. The setup phase occurs during an in-person clinical visit, where a medical practitioner trains the patient and captures a personalized **reference image** for each target joint. A 10-minute session is typically sufficient. This step is essential, as probe positioning varies based on the patient's anatomy and must be personalized to ensure accurate self-acquisition. During training, the practitioner demonstrates how to operate the system, provides basic instructions for initial probe placement, and explains how to interpret the guidance interface. While acquiring the reference image, the practitioners sets the US acquisition parameters and acquires an image (see Fig. 2a). From this, anatomical markers specific to each scan are automatically extracted using object detection. Once the practitioner verifies the quality of the image, it is saved to serve as the reference for future acquisitions.

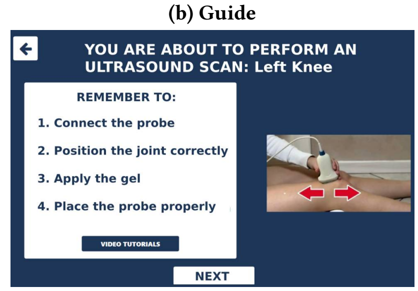
During the self-acquisition phase, guidance is provided through two complementary interface modalities. On the right side of the screen (see Fig. 2b), the live ultrasound feed is overlaid with bounding boxes that highlight detected anatomical markers (solid lines). The patient is instructed to align these boxes with corresponding target areas (dashed lines) of the same color, which are derived from the reference image. For example, in Fig. 2b, the solid box indicates the current positions of the patella, while the dashed box shows its expected position. To support alignment along the longitudinal axis, the left frame includes an image of the joint that dynamically updates to indicate the direction in which the probe should be moved. When the system detects a misalignment, an arrow appears on the image pointing toward the correct adjustment direction. For example, if the probe is positioned too proximally on the thigh, the image displays an arrow pointing distally, guiding the user to move the probe downward.



(a) Automate



(b) Guide



(c) Remind

Figure 2: Automate-guide-remind principle visualization through GAJA app.

3.2.2 The automate-guide-remind principle. GAJA was designed with the *Automate-Guide-Remind* design principle [6]. According to this principle, as many actions as possible should be **automated**. For example, as shown in Fig. 2a, when the practitioner acquires the reference image, GAJA saves acquisition parameters that are automatically loaded during self-acquisition. The actions that cannot be automated, and that require extensive practice and deep domain knowledge, which usually only medical practitioners acquire during their training, should be **guided** (Fig. 2b), meaning that the system should provide automatic instructions in real-time on how to use the system. Similarly, before each acquisition, the patient is guided through an anamnesis questionnaire, which collects information about recent activities or potential trauma. These details are sent to the practitioner along with the ultrasound images to support clinical evaluation. For the remaining actions, which cannot be automated or guided, clear **reminders** (Fig. 2c) should be automatically provided by the system. These actions should only include those that are easy to explain to the patient and that the patient can easily complete.

3.3 Joint-specific guidance

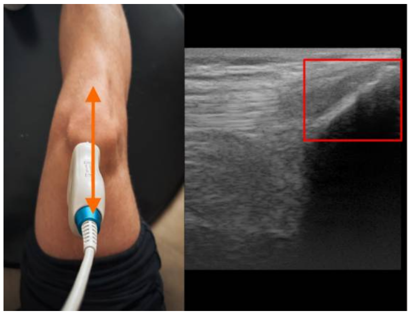
GAJA requires to identify stable and interpretable anatomical markers that can guide probe alignment. Across all joints, we assume certain degrees of freedom—such as probe rotation along its central axis—are constrained or fixed through physical setup or instructional support. We focus instead on translational movements that the patient can control and that the system can monitor and guide through the real-time detection of anatomical markers.

For each joint, we select markers that are (i) consistently visible in ultrasound images, (ii) anatomically stable across patients, and (iii) sensitive to variations in probe position or joint configuration. These markers support the implementation of the Automate–Guide–Remind principle: using real-time object detection to guide probe placement where possible, and offering reminders or static instructions where automation is not feasible. Fig. 3 shows an example of the probe positioning for each joint, alongside the corresponding ultrasound image with anatomical markers highlighted in red.

3.3.1 Knee acquisition. For the knee, the user sits on a chair resting the foot on another chair: then positions the probe longitudinally on the leg, as shown in Figure 3a. Micro positioning is guided by the relative position of the patella in the US image.

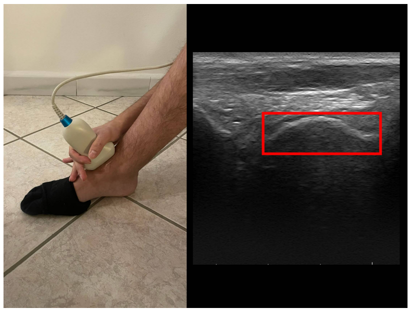
3.3.2 Elbow acquisition. The patient flexes the elbow to approximately 90°, keeping the ulna perpendicular to the floor, and the humerus parallel (see Fig. 3b). The probe is aligned longitudinally along the upper arm, and correct positioning is confirmed when the olecranon fossa appears clearly between the surrounding anatomical structures. Longitudinal probe movement is guided by tracking the ulna, which offers a consistent visual reference and thus is used as the marker.

3.3.3 Ankle acquistion. For the ankle, the patient is seated with the heel resting on a stable surface, the ankle extended, and the knee flexed to allow access to the anterior tibio-talar joint (see Fig. 3c). Probe alignment is guided using the talus, chosen for its distinctive and stable ultrasound signature. Due to the limited field of view of portable probes, simultaneous visualization of the talus dome and distal tibia is used as a compromise to ensure diagnostic quality.



(a) Knee

(b) Elbow



(c) Ankle

Figure 3: Joint and probe positioning, alongside the collected image and its marker (red box).

4 Conclusion and limitations

Portable ultrasound devices represent an opportunity for advancing e-health services, especially in the management of chronic conditions like hemophilia, where regular and timely joint monitoring is critical. Despite their potential, the broader adoption of self-acquisition workflows remains limited due to the lack of practical solutions that allow patients to independently capture clinically relevant images without increasing the workload for medical professionals. GAJA addresses this gap by offering an accessible, cost-effective, and user-centered system specifically designed to support hemophilic patients in performing ultrasound acquisitions autonomously.

In this demo, we showcase an updated version of GAJA that extends its functionality beyond the knee to include elbow and ankle joints. The demo presents an innovative form of interaction, in which the relative position of markers in US images is used to guide the user to correctly position to probe, without the need for remote assistance by a medical expert. This extension was informed by a detailed analysis of the anatomical and procedural characteristics of each articulation, conducted in close collaboration with medical experts. Based on this analysis, we designed dedicated acquisition workflows for each joint, considering joint-specific constraints and patient motor capabilities.

Acknowledgments

This project was partially supported by TEMPO – Tight control of treatment efficacy with tElemedicine for an improved Management of Patients with hemOphilia project, funded by the Italian Ministry of University and Research, Progetti di Ricerca di Rilevante Interesse Nazionale (PRIN) Bando 2022 - grant [2022PKTW2B] and by the nonprofit Angelo Bianchi Bonomi Foundation; Sobi, Bayer and Roche provided unrestricted grants to the Angelo Bianchi Bonomi Foundation (JoinMi project). Preliminary work on this system was also partially supported by the MUSA (Multilayered Urban Sustainability Action) and by the FAIR (Future Artificial Intelligence Research) projects both funded by the NextGeneration EU program.

References

[1] Peter Aguero, Richard FW Barnes, Andres Flores, and Annette von Drygalski. 2023. Teleguidance for Patient Self-Imaging of Hemophilic Joints Using Mobile Ultrasound Devices: A Pilot Study. *Journal of Ultrasound in Medicine* 42, 3 (2023), 701–712.

[2] Dragan Ahmetovic, Alessio Angileri, Sara Arcudi, Claudio Bettini, Gabriele Civitarese, Marco Colussi, Andrea Giachi, Roberta Gualtierotti, Sergio Mascetti, Matteo Manzoni, et al. 2024. Insights on the development of practice, a research-oriented healthcare platform. In *2024 IEEE International Conference on Smart Computing (SMARTCOMP)*. IEEE, 380–385.

[3] Yanick Baribeau, Aidan Sharkey, Omar Chaudhary, Santiago Krumm, Huma Fatima, Feroze Mahmood, and Robina Matyal. 2020. Handheld point-of-care ultrasound probes: the new generation of POCUS. *Journal of cardiothoracic and vascular anesthesia* 34, 11 (2020), 3139–3145.

[4] Maximilian Berlet, Thomas Vogel, Mohamed Gharba, Joseph Eichinger, Egon Schulz, Helmut Friess, Dirk Wilhelm, Daniel Ostler, Michael Kranzfelder, et al. 2022. Emergency telemedicine mobile ultrasounds using a 5G-enabled application: development and usability study. *JMIR Formative Research* 6, 5 (2022), e36824.

[5] Alan T Chiem, George W Lim, Amir P Tabibnia, Andrea S Takemoto, Daniel M Weingrow, and Jacqueline E Shibata. 2021. Feasibility of patient-performed lung ultrasound self-exams (Patient-PLUS) as a potential approach to telemedicine in heart failure. *ESC Heart Failure* 8, 5 (2021), 3997–4006.

[6] Marco Colussi, Sergio Mascetti, Dragan Ahmetovic, Gabriele Civitarese, Marco Cacciatori, Flora Peyvandi, Roberta Gualtierotti, Sara Arcudi, and Claudio Bettini. 2023. GAJA-Guided self-Acquisition of Joint ultrAsound images. In *International Workshop on Advances in Simplifying Medical Ultrasound*. Springer, 132–141.

[7] Giulia Corte, Sara Bayat, Koray Tascilar, Larissa Valor-Mendez, Louis Schuster, Johannes Knitza, Filippo Fagni, Georg Schett, Arnd Kleyer, and David Simon. 2021. Performance of a handheld ultrasound device to assess articular and periarticular pathologies in patients with inflammatory arthritis. *Diagnostics* 11, 7 (2021), 1139.

[8] Heather Culbertson, Julie M Walker, Michael Raitor, Allison M Okamura, and Philipp J Stolka. 2016. Plane assist: the influence of haptics on ultrasound-based needle guidance. In *Medical Image Computing and Computer-Assisted Intervention–MICCAI 2016: 19th International Conference, Athens, Greece, October 17-21, 2016, Proceedings, Part I 19*. Springer, 370–377.

[9] Nicole M Duggan, Nick Jowkar, Irene WY Ma, Sara Schulwolf, Lauren A Selame, Chanel E Fischetti, Tina Kapur, and Andrew J Goldsmith. 2022. Novice-performed point-of-care ultrasound for home-based imaging. *Scientific Reports* 12, 1 (2022), 20461.

[10] Roberta Gualtierotti, Andrea Giachi, Chiara Suffritti, Luca Bedogni, Francesco Franco, Francesco Poggi, Sergio Mascetti, Marco Colussi, Dragan Ahmetovic, Valentina Begnozzi, et al. 2024. Optimizing long-term joint health in the treatment of hemophilia. *Expert Review of Hematology* 17, 10 (2024), 713–721.

[11] Margaret W Hilgartner. 2002. Current treatment of hemophilic arthropathy. *Current opinion in pediatrics* 14, 1 (2002), 46–49.

[12] QH Huang, YP Zheng, MH Lu, and ZR Chi. 2005. Development of a portable 3D ultrasound imaging system for musculoskeletal tissues. *Ultrasonics* 43, 3 (2005), 153–163.

[13] Gi-Duck Kim, Changhan Yoon, Sang-Bum Kye, Youngbae Lee, Jeeun Kang, Yangmo Yoo, and Tai-Kyong Song. 2012. A single FPGA-based portable ultrasound imaging system for point-of-care applications. *IEEE transactions on ultrasonics, ferroelectrics, and frequency control* 59, 7 (2012), 1386–1394.

[14] Paul B McBeth, Innes Crawford, Michael Blaivas, Trevor Hamilton, Kimberly Musselwhite, Nova Panebianco, Lawrence Melniker, Chad G Ball, Luna Gargani, Carlotta Gherdovich, et al. 2011. Simple, almost anywhere, with almost anyone: remote low-cost telementored resuscitative lung ultrasound. *Journal of Trauma and Acute Care Surgery* 71, 6 (2011), 1528–1535.

[15] Eyal Schneider, Netta Maimon, Ariel Hasidim, Alla Shnaider, Gabrielle Migliozzi, Yosef S Haviv, Dor Halpern, Basel Abu Ganem, and Lior Fuchs. 2023. Can Dialysis Patients Identify and Diagnose Pulmonary Congestion Using Self-Lung Ultrasound? *Journal of Clinical Medicine* 12, 11 (2023), 3829.

[16] Shih-Yu Sun, Matthew Gilbertson, and Brian W Anthony. 2013. Computer-guided ultrasound probe realignment by optical tracking. In *2013 IEEE 10th International Symposium on Biomedical Imaging*. IEEE, 21–24.