

6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the
Affiliated Conferences, AHFE 2015

Ultrasound system typologies, user interfaces and probes design: a review

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Abstract

The present review paper aims to give insights regarding what is available now, and will be in the next future, on the Market in terms of Ultrasound (US) system User Interfaces characteristics and peculiarities; US system typologies and probe typologies. Moreover, insights regarding ergonomics evaluation technologies and techniques for US systems, User Interface and transducers design evaluation, will be provided as well. The User interface ergonomics of US systems and probes is of primary importance due to the increased use in the everyday clinical practice even by non-sonographers, and the higher attention to the Work-related Musculoskeletal Disorders (WRMSD). A large overview and review of market data, side by side tests, websites, interviews to US users, marketing and sales professionals, scientific and educational publications was carried out in order to collect all available data as well as to show and describe them to the reader. Nowadays US market offers many different typologies of systems and probes, with different prices, features, quality level and targets of use. Users have to be aware to increase their level of knowledge in order to perform the best choice in terms of price/performance ratio and in terms of ergonomics and workflow requirements. The same level of knowledge is necessary also for other stakeholders of the US imaging Lab and purchasing/test decision phases such as Clinical and Biomedical Engineers involved in technical decision related to capital equipment and their maintenance. Final users expect technical innovations every 6-12 months in order to ensure technical-clinical improvements and company commitment to research and customer focus. Such characteristics are important clues showing a fast moving of the US market from a capital equipment basis to a more mass-consumer approach characterized by fast innovations, quick obsolescence and consumer prone attitude to system rotation in order to have always the more up-to-date technology, product, probe available on the Market.

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Peer-review under responsibility of AHFE Conference

Keywords: Ergonomics; US system market; Work-related musculoskeletal disorders

Nomenclature

WRMSD	Work-related Musculoskeletal Disorders
US	Ultrasound
UI	User Interface(s)
TS	Touch Screen

1. Introduction

Diagnostic Ultrasound (US) systems have consistently changed their position and diffusion among the Diagnostic Imaging Market in the last decade. Nowadays US systems and related probes and technologies have lower prices and higher quality both regarding diagnostic capabilities and general appearance: they are more user-friendly, with higher quality user interfaces, major attention to design, and a more functional and up-to-date layout.

US systems are much more common than some years ago. More and more US investigations are performed per day worldwide with productivity being one of the main key drivers for users [1]. Moreover, US systems are spreading due to US technological improvements, reduced costs, and the economic contraction experienced by many developed countries. From a price/performance point of view, US has begun to deal with big systems (such as Computed Tomography and Magnetic Resonance Imaging) in many countries and for many applications (e.g. in Chinese hospitals it is common the presence of a department completely dedicated to diagnostics US for all the different clinical applications including also Interventional Radiology performed under US real-time guidance).

US systems are used in many different environments (Hospitals, Echo Labs, Emergency and Surgery rooms, Ambulances and Helicopters, Imaging Labs on trucks) and for many clinical applications (Adult Cardiology, Pediatric Cardiology, Neonatology, Vascular, Adult cephalic, Ophthalmic, Abdomen, Small Parts, Thyroid, Urology, Musculoskeletal, Obstetrics, Gynecology, Breast, Lung ultrasound, Intraoperative, Neurosurgery, Veterinary application both for Large and Small Animals, Fusion Imaging for traditional and non-traditional applications both for diagnostic and interventional purposes, Interventional radiology, Critical care, Emergency). Furthermore, the patient population can be represented by Fetal, Neonatal, Pediatrics, Adult, Small animal, Large animal, while the user profile, intended to cover the full range from novices to expert users, is populated by Sonographers, Medical Doctors, Radiologists, Surgeons, Veterinary practitioners, Midwives, Paramedics.

Due to their wide diffusion, US systems are used also by non-sonographers; therefore, a higher level of usability is requested with rapidity in recent years (Fig. 1 (a)), with the creation of different typologies of systems in terms of shapes, dimensions, controls, technologies and usability. The same can be said in terms of US probe design and transducer typologies: they have to cover a wide range of uses and different clinical applications for different patients and different characteristics.

Furthermore, the Veterinary Diagnostic Market is also expanding and requiring systems covering all the segments and uses (large and small animals, pets, cattle for pregnancy check, etc.), as well as different probes and input/output interfaces.

These new paths in the use of US have completely changed the customers' approach to US technologies and devices as well as the market perception of such diagnostic technology which is the only one, in the field of complex diagnostic imaging, characterized by a real-time nature.

From a market segmentation point of view, US systems are divided into two main typologies, cart-based and portable, each one divided into three different groups: High-End and Premium segment (Fig. 1(b)), Mid segment, and Value segment. The belonging of a certain product to one of the different segments is driven by its price strategy and involved technologies, its layout and design, and its general quality and perception (also driven by its brand-related characteristics).

While the basic US diagnostic modalities are quite common among almost all the US products available today on the market (at least considering systems belonging to the same market segment), the major differences in terms of product perception are done by additional features and characteristics (often "non-strictly" diagnostics).

The perception of an advanced technology is, in many situations, characterized also by its user friendliness and

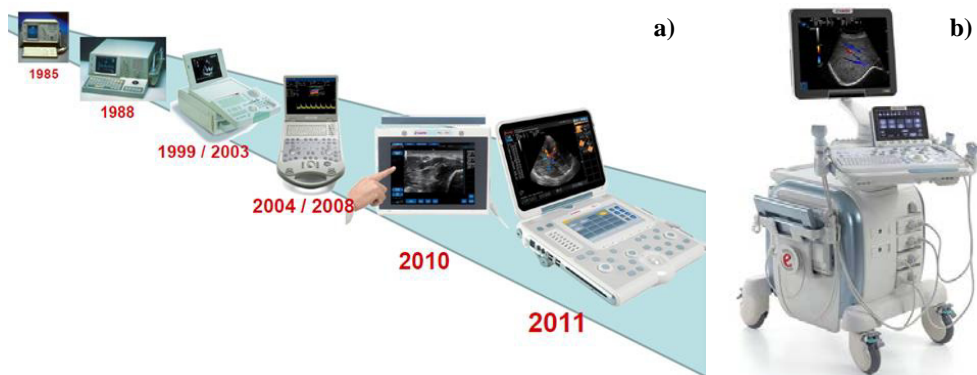


Fig. 1. (a) Evolution of Portable US units and UI from 1985 to 2011; (b) Example of Premium Segment US cart-based system.

its graphical representation and design quality. An US system is often perceived as a high level scanner for its general design and graphical representation of its user interface; the system typology, layout and design represent at least the first sight outlook. These new paths among the ultrasound systems have changed a lot in relation to what a customer expects from a product and how a tool or its technology is perceived.

Many of the characteristics, tools and technologies considered in this paper have been developed in order to add features to the basic US diagnostic modalities; they can be important for the diagnostic capabilities of the system and, moreover, for the customer perception of the US system quality and inner technology.

The present review paper aims to give insights regarding what is nowadays available on the market, with also possible insight related to the near future, in terms of:

- US system User Interfaces (UI) characteristics and peculiarities,
- US system typologies and technologies,
- Probe typologies,
- Ergonomics evaluation technologies and strategies used so far for US systems, User Interface and Transducers Design

The UI ergonomics of the US systems and probes is nowadays of primary importance due to the increased use of US systems in the everyday clinical practice even by “non-sonographers” as well as the increased attention to the problem of Work-related Musculoskeletal Disorders (WRMSD) for sonographers [2, 3].

2. Material and methods

A large overview and review of market data and websites as well as interviews to US users, marketing and sales professionals, scientific and educational publications, was carried out in order to collect data and to both analyze and organize them as presented in this study.

2.1. Issue of ergonomics in sonography

The issue of US systems Ergonomics is treated in many Standards and Guidance Documents from Regulatory Organizations, Healthcare Institutions and Sonographers Associations, as WRMSD are widely common among sonographers. The percentage of sonographers reporting consequences of pain and discomfort is close to 80% within the first five years of entering the profession (SDMS Data - <https://www.sdms.org/msi/osha.asp>). Neck, shoulder, wrist, hand, back and eyes are the most common areas of discomfort and pain for US users. So far, no industrial standards or technical guidelines are dedicated to the US systems design; therefore, numerous workflows and different way of usage are present within the US systems available on the market. From the user point of view the best design has to be intuitive and less stressful during its operation and handling.

Today the tendency to reduce the complexity of US system UI is very common and goes towards the reduction of the levels/number of controls, more confidence in reducing human errors, and the increase of the numbers of reachable and highly reconfigurable UI.

2.2. Issues of US system and probe design

A multifactorial, multidisciplinary approach is needed for system and probe ergonomics design, because the US Ergonomics and Design is a complex task involving many aspects, such as:

- User's level of technical and clinical experience;
- User's habit to a product and general personal attitude;
- Clinical application considered;
- Clinical workflow to be followed (depending on country, hospital - clinical department rules, etc...);
- Type of US system and market segment.

During the scanning protocol, the US system has to be usable with only one hand, while the other one handles the probe. The real-time nature of US forces the designer to develop controls to be easily found also when the attention is focused on the patient, while using only one hand and looking at the system monitor, in clinical or emergency setting, in a lab or on the field, depending on the US system used.

The goal of any US system producer is to create easy-to-be-used systems as well as comfortable probes in order to make the operator more concentrate on the patient, since the system is perceived as intuitive, with a reduction of both physical and mental stress, saving energy for more productivity and enhanced quality life for both users and patients.

2.3. Main technologies used for system and probe design definition and evaluation

Various measurements as well as design and workflow evaluations with a multifactorial approach are made by considering different outputs and analysis/measurement technologies regarding biomechanical analysis and cognitive usability assessment

- Motion Analysis: optoelectronics cameras are used to follow user movements while performing real clinical protocols, in order to evaluate possible workflows, system design and areas and traces covered by user arms;
- Eye tracking: to analyze user's focus areas in order to understand where controls and visual feedbacks are more suitable for reducing the user's visual stress;
- Superficial Electromyography: to measure user's muscle activity while both system and probe are being used. Wireless sensors are used in order to free completely the user's movements during the tests;
- Digital Human Modeling: digital models of real users are used in order to test design ideas at the early stage of CAD (Computer Aided Design) level, within digital worlds created ad hoc;
- Direct interviews to users;
- Observational studies with camera recordings triggered by bio-mechanical test inputs.

3. Results

3.1. US system user interfaces

US systems UI can be characterized by different input/output technologies and peculiarities [4]. The most common solutions available today on the US system market are the following:

- Touch Screen (TS) on main screen: the same monitor used for US image visualization is also used as input interface with touch screen capabilities (<http://www.esaote.com/ultrasound/ultrasound-systems/p/mylab-one->

- touch/). UI can also have physical controls (usually positioned around the monitor which is TS too – <http://www.sonosite.com/nanomaxx>), but they can also be touch screen-based, with no physical controls;
- Traditional: physical control panel and Soft Key Menu on the main screen with dedicated interactive controls (Soft Keys – <http://www.esaote.com/ultrasound/ultrasound-systems/p/mylab-25-gold/>);
 - TS within control panel (<http://www.esaote.com/ultrasound/ultrasound-systems/p/mylab-alpha/>);
 - Main screen with touch capabilities in the lower area (<http://www.hitachi-aloka.com/products/preirus/>);
 - US system with a Control Panel completely TS (separated from the main screen where the US image is shown). In some cases TS has some etched marking for primary controls in order to assist the user in locating key functions without looking at the screen (<http://www.edanmedical.com/poc/product.php>)
 - Laptop input systems only (<http://www.pcultrasound.com/products/eb128/index.html>)
 - Remote Controller which replies part of the user interface of the US system, useful especially for Operating Rooms (Fig. 2);
 - Voice controls (http://www.healthcare.philips.com/it_it/products/ultrasound/technologies/ergonomic_setup.wpd);
 - Arm-held US system with user programmable controls on the handle (Fig. 3 (a));
 - US probe with user programmable controls on the probe body (Fig. 3 (b)).

The concept of TS is widely used in everyday life within lots of technological gadgets and input devices. Anyway, the US system interface is widely different with respect to the other “consumer electronics” systems. The US device is used, at least during the real-time acquisition, with one hand only (the other one has to handle the transducer) with the operator usually not positioned in front of the US system control panel. Therefore, the US UI cannot follow the same design rules of the everyday life technological gadgets. Additionally, the US system UI has to be designed in order to be also used in situations of low level of illumination (as many imaging labs are) in order to see the US image in a better way. The touch screen as input device is anyway common among console-based US systems: in the last ten years almost all the manufacturers have integrated touch screens at least in their high level systems, but it has been introduced only recently among the portable US units [1].

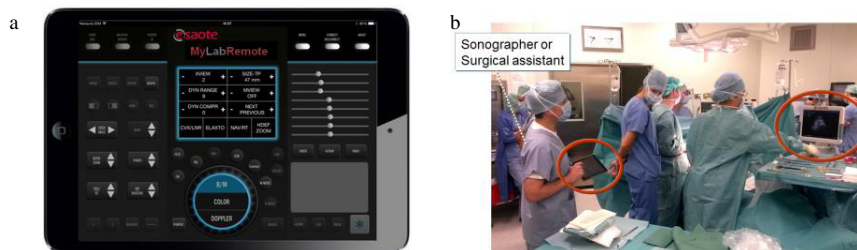


Fig. 2. (a) Esaote MyLabRemote; (b) use of Esaote MyLabRemote in a operating room.



Fig. 3. (a) Arm-held US system (Esaote MyLabONE) with user programmable controls on the handle; (b) US probe with user programmable controls on its body.

3.2. Automation in US

One of the most recent trends in US workflow improvements is the increasing number of automatic scanning tools, related to automatic measurements (3D-4D VRA Counting: <http://www.esaote.com/ultrasound/ultrasound-systems/p/mylab-classic/>), tutorials on board (MyLibrary: http://www.esaote.com/uploads/tx_esatenews/ENewsVET_169004400-01-lowres.pdf), examination protocols (http://www3.gehealthcare.com/en/products/categories/ultrasound/logiq/logiq_e9/video_scan_assistant), macro recorders (eTouch: http://www.esaote.com/en-BE/ultrasound/ultrasound-systems/p/mylab-alpha/#_t_2).

3.3. US system typologies

In order to fit in any possible clinical setting, taking into consideration different clinical applications and user/patient typologies, the following US system types can be found in the market:

- Portable US Systems (<http://www.esaote.com/ultrasound/ultrasound-systems/p/mylab-alpha/>)
- Wearable and Arm-held US Systems (<http://www.esaote.com/ultrasound/ultrasound-systems/p/mylab-one-touch/>; <http://www.esaote.com/veterinary/vet-systems/p/tringa-linear-vet/>)
- Console-based Systems (Mainframe; cart-based – <http://www.esaote.com/ultrasound/ultrasound-systems/p/mylab-twice/>)
- Examination-Targeted US Systems (http://www.esaote.com/ultrasound/ultrasound-systems/p/mylab-one-touch/#_t_2)
- Hand-held US systems (<https://vscan.gehealthcare.com/introducing-vscan-family>)
- Smartphone-based US systems: US probe plugged within a Smartphone (<http://www.signostics.com.au/>)
- Laptop-based US systems (<http://www.terason.com/t3000/>)
- Vet system with goggles for viewing (<http://www.international.bcftechnology.com/products/bug-goggles>)
- Wireless Probe US Systems (<http://www.healthcare.siemens.com/ultrasound/ultrasound-point-of-care/acuson-freestyle-ultrasound-system>)
- US Research-only system (<http://www.msdlab.dinfo.unifi.it/CMpro-v-p-19.html>)
- Handheld US for Peripheral Intravenous Placement (<http://bkultrasound.com/products/sonicwindow>)
- Bladder scanners for bladder volume measurement (http://www.laborie.com/upload/ProductsAttaches/9d9b6359.pdf/_as/BladderVu%20LETTER%20Lowres%2005_06_2013.pdf)
- Ophthalmic dedicated US systems (https://www.optos.com/Global/documents/OptosScan3000_Brochure.pdf)
- Research dedicated US systems for small animals, characterized by extremely high frame rate acquisition capabilities (<http://www.visualsonics.com/products/vevo-770>)

3.4. Ultrasound transducers

The selection of the appropriate probe (Fig. 7) is the first action to be taken before starting any US exam. The choice of the proper probe depends on the exam type, on the scan depth and the anatomical structure of the patient. Different transducers have been developed for different clinical applications and patient/examination characteristics.

- Phased array (Adult, Pediatric and Neonatal)
- Convex and Microconvex (classification depending on the ray of curvature of the array)
- Linear array
- Linear array with extended width (9 – 10cm)
- Laparoscopic
- Intraoperative
- Trans-esophageal (Adult and Pediatric)
- Pencil Doppler (blind)
- Endocavity (end fire and double transducer –transrectal – convex/linear)

- Electro-mechanical 3D (linear, convex, endocavity, linear with parallel acquisition)
- Convex with Biopsy Slot (0°, 5°, 15°)
- Linear probe with 0° Biopsy slot
- Veterinary dedicated Probes
- Intravascular probes (IVUS – http://www.volcanocorp.com/products/ivus-imaging/#.VQ_8EI4kKbQ)
- Trans-esophageal (TEE) for long time monitoring (<http://imacorinc.com/htee/products/claritee.html>)
- 3D Matrix probes (Phased, Convex or TEE)
- TEE mini esophageal probe (<http://www.olderdelft.nl/products/minimulti-pediatric-tee-transducer/item17>)
- 3D transrectal probe (http://www.bkmed.com/3dart_transducer_8838_en.htm)
- Automate Breast Ultrasound ABVS (<http://www.healthcare.siemens.com/ultrasound/radiology/acuson-s2000-abvs-ultrasound-system>)
- Water-bath systems for Breast examination (<http://www.delphinusmt.com/our-technology/softvue-system>)
- Single probe with double transducer
(http://www.3gehealthcare.com/en/products/categories/ultrasound/vscan_family/vscan_with_dual_probe)

During the real-time acquisition, the US transducer is a “fixed” interface for the operator; therefore, during the scanning protocol, the US system has to be usable with only one hand, while the other one has to handle the probe. New design concept has been developed in the recent years in order to reduce scanning fatigue and the related WRMSD. Transducers with a dual-possibility hand grip (appleprobe design) are available (pinch grip and palmar grip) in order to provide a neutral wrist position reduced fatigue and easier handling of the probes [5].

One important aspect strictly related to probe typologies and ergonomics is represented by biopsy kits which are available for different uses, body areas and from Fine Needle Aspirations (FNA) up to percutaneous interventions and core biopsies (Fig. 8 (a)).

Another accessory that can be attached to the US probe is the support for navigation systems (usually electromagnetic or optical) for real-time fusion imaging. This kind of accessory is used to gain the highest position precision with the lowest impact on probe ergonomics and handling possibilities. A single electromagnetic sensor, secured through a highly ergonomic mounting bracket on the probe, enables a high level of spatial precision ensuring a comfortable workflow which does not need probe handling changes and/or major probe weight changes (Fig. 8 (b)). When cleanability and sterility are issues of main importance, probe and also whole system sterile covers can be used.



Fig. 7. Different transducers developed for different clinical applications and patient/examination characteristics.

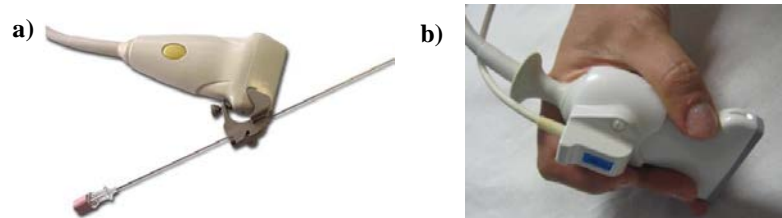


Fig. 8. (a) Biopsy kit; (b) Support for navigation systems for real-time fusion imaging mounted on the US probe.

4. Discussion and conclusion

Nowadays US market offers many different typologies of systems and probes, with different prices, features, and quality level and targets of use. Users (Medical Doctors and Sonographers mainly, but also nurses and paramedics) have to be aware and increase their level of knowledge in order to perform the best choice in terms of price/performance ratio and in terms of ergonomics and workflow requirements. The same level of knowledge is necessary also for other stakeholders of the US imaging Lab and purchasing/test decision such as Clinical and Biomedical Engineers involved in technical decision related to capital equipment and their maintenance. US market has changed a lot in the last 10 years in terms of performances, products, prices and technical innovations which are expected by the final users each 6/12 months in order to ensure technical-clinical improvements and Company commitment to research and customer focus. Such characteristics are important cues of the fast moving of the US market from a capital equipment basis to a more mass-consumer approach characterized by fast innovations, quick obsolescence and consumer prone attitude to system rotation in order to have always the more up-to-date technology, product, probe or even “concept” available.

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