Development of the diagnostic ultrasound system LISENDO 880

Tetsuo Watanabe
Masato Eda
Tomoaki Chono
Masanori Hisatsu
Takashi Fujii
Takashi Kayama

1) Products R&D Division 1, Diagnostic R&D Division, Hitachi, Ltd. Healthcare Business Unit
2) Engineering R&D Division 1, Diagnostic R&D Division, Hitachi, Ltd. Healthcare Business Unit
3) Marketing Division, Diagnostic Systems Division, Hitachi, Ltd. Healthcare Business Unit

Hitachi, Ltd. Healthcare Business Unit (HHBU) was formed as the healthcare section of Hitachi group in April 2016. The premium ultrasound system, “LISENDO*1 880”, is the first model to be marketed from HHBU. LISENDO 880 has been developed to embrace the functions and performance dedicated to cardiovascular applications, establishing Hitachi’s reputation in this field.

1. Introduction
1.1 Background to the development
Since 2014, we have approached the cardiovascular field by diagnostic ultrasound system ProSound*2 F75 PremierCV.
Despite our continued efforts, we have encountered cases that cannot be explained with conventional cardiac functional measurements, such as patients with heart failure whose left ventricular ejection fraction (EF) is maintained. To provide solutions to clinical challenges such as these by visualization and quantification of cardiac hemodynamics, we have developed “LISENDO 880” (Figure 1), a premium-class diagnostic ultrasound system dedicated to the cardiovascular field.

1.2 The origin of the name “LISENDO 880”
The word “LISENDO” combines the English word listen as in “listen to the sound” and the Greek word endo meaning “inside,” to create “LISENDO”: “listening to the sound inside the body”. “LISENDO” is our brand name for diagnostic ultrasound systems dedicated to the cardiovascular field.
Hitachi introduced the world’s first diagnostic ultrasound system equipped with Color Doppler in 1983, namely “SSD-880”. By nurturing our original aims and reinvigorating our pursuit of the understanding of hemodynamics, we have used again the same number from “SSD-880” in the product name.

1.3 Product concepts
The development of LISENDO 880 has been based on three main concepts – “Pure Image,” “Seamless Workflow,” and “Your Application” – to provide customer value as a premium-class platform dedicated to the cardiovascular market providing “performance,” “usability,” and “application.”
2. Pure Image

Returning to the basics of diagnostic ultrasound, we have sought improved performance in the three major imaging areas – spatial, contrast, and temporal resolution – advancing performance using the Pure Symphonic Architecture technology (Figure 2).

2.1 Electronic sector transducer “S121”

We have developed a new electronic sector transducer, “S121”, to meet users’ requirements for usability and high performance (Figure 3).

With a compact shape, the boot section can be held comfortably and firmly in a variety of different ways. The small footprint of the acoustic lens and well-considered shape of the edge allow the operator to use different windows whilst reducing discomfort to the patient. Care has also been taken in the choice of diameter and weight of the cable so as not to impact on the examination.

For performance, consideration has been given to the probe’s frequency characteristics (Figure 4) to strike a balance between a broad bandwidth contributing to spatial resolution, and the high sensitivity required in the Doppler mode. To achieve this balance i.e., effective transmission and reception over a wide range from low to high frequencies, a single-crystal piezoelectric material with an electromechanical coupling coefficient of more than 90% is used.

2.2 “HI Framerate” and “eFocusing” realized by the Variable Beamformer “HI Framerate”

To improve the frame rate, conventional models employ multidirectional simultaneous reception technology to obtain multiple reception beams from a single transmission. Due to limitations imposed by the hardware, however, the simultaneous reception of multidirectional beams is possible only from two to four directions. In this simple model, furthermore, the higher frame rate is a tradeoff with reduced lateral resolution.

As shown in Figure 5, LISENDO 880 is equipped with “HI Framerate,” a multidirectional simultaneous reception technology that can generate multiple reception beams from one transmission. This strikes a balance between high spatial resolution and high temporal resolution in B-mode and Color Doppler imaging (Figure 6), and also contributes to improved detection for generation of Doppler waveforms.

Any regurgitant flows will move spatially in synchronization with the beating of the heart. It is often required to measure a regurgitation only several millimeters in size, located at a depth of 10 cm from the body surface. To capture such a regurgitation and display the Doppler waveforms with high sensitivity, first it is required to set the position and angle of the transducer so that the regurgitant jet remains within the scanning plane. Secondly, the Doppler sample gate must be set precisely over the regurgitation (Figure 7). The operator receives assistance for both these tasks in the Color Doppler images created by “HI Framerate” that strike a balance between high spatial resolution and high temporal resolution.

Figure 2: Pure Symphonic Architecture technology

Figure 3: The electronic sector transducer S121

Figure 4: Frequency characteristics of S121 transducer

Figure 5: Multidirectional simultaneous reception technology “HI Framerate”
As a result, improved Pulse Wave (PW) and Continuous Wave (CW) Doppler waveforms can be detected.

“eFocusing”

In beam forming during reception for diagnostic ultrasound systems, the signals received by the transducer from each sample point along the reception beam are given a delay time before being phased and summed, so that the resulting reception signals are focused for all sample points. This is dynamic focus technology on reception. In transmission beam forming on the other hand, a single transmission focus point is set, and the transmission beam is formed by giving a delay time to each transducer element at the time of transmission. Consequently, as shown in Figure 8, the transmission beam width is narrow and the lateral resolution good at a depth near the transmission focus point, but at other depths away from the focus point, lateral resolution deteriorates.

“eFocusing” reduces transmission focus dependency using “HI Framerate,” a multidirectional simultaneous reception technology. As shown in Figure 9 (a), the position of the transmission beam is shifted such that the reception beam fields resulting from each single transmission overlap, with the result that a synthetic reception beam can be created. This effect can be described taking scattering point ● as an example. In conventional transmission beam forming, if B-mode images are created from simultaneous multidirectional reception signals obtained from a single transmission, the lateral resolution of the image of point ● is low from each transmission wavefront as shown in Figure 9 (b), in the same manner as the lateral resolution deteriorates at a depth away from the transmission focus point. However, by synthesizing the reception signals using the phase information from each transmission, the phases will match at the position of point ●. In other positions, the signal components attributable to this scatterer are canceled out through the process of synthesis and result in B-mode images with improved lateral resolution as shown in Figure 9 (c). This process of synthesis can be interpreted as transmission beam focusing for sample points at every depth, i.e., realizing dynamic transmission focusing. Since reception also uses dynamic focusing as in the conventional models, “eFocusing” achieves dynamic focusing in both transmission and reception. Furthermore, the reception signals synthesized from multiple transmissions contribute to an improved signal-to-noise ratio and thus improved penetration. Examples of B-mode images obtained by “eFocusing” are shown in Figure 10.

Thanks to the effect of dynamic focusing in transmission and reception, “eFocusing” reduces the transmission focus dependency experienced in conventional models, and eliminates the need to set a transmission focus depth. Therefore, in addition to providing high-quality B-mode images with excellent penetration, it also contributes to improved workflow by reducing examination time.
2.3 High quality imaging achieved by Active Backend

with a wide range of image quality parameter
adjustments to meet the individual needs of exam-
iners and patients.

Ultrasound diagnostic imaging can be examiner-depen-
dent in terms of differences in adjustment and preference. It
it can also be patient-dependent in terms of difference in body
physique and constitution. This brings about the need for a
wide range of image parameter adjustments.

LISENDO 880 is programmed with multiple image ad-
justment parameters that have been refined through the
development of our previous platform portfolio, including
the ProSound, HI VISION and ARIETTA™ series, and are
thus capable of offering a wide range of image quality ad-
justments to provide images suited to the various modes of
diagnosis, ranging from quantitative to morphological (Fig-
ure 11), and overcoming the long-held challenge of reducing
examiner-and patient-dependency.

- Qualitative diagnosis: Images with a wide dynam-
ic range, capable of visualizing the detailed information
of the myocardium. Allows evaluation of the heart wall
and assessment of its properties.
- Morphological diagnosis: High black and white con-
trast, structure-emphasized images. Main purpose is mor-
phological understanding.

2.4 Improvement of contrast resolution by organic EL
monitor

B mode, the abbreviation of Brightness mode, is the basic
diagnostic ultrasound mode. The B-mode image depicts the
internal structure of a biological tissue in shades of gray, or
gradations of white and black. Among the important indica-
tors for this gray scale performance is contrast resolution. If
the monitor that displays ultrasound images has a poor gray
scale – i.e., if the contrast ratio is low – the system cannot
achieve high contrast resolution.

Organic Electro-luminescence (EL) monitors are made
up of EL elements which emit light in a process known as
electrophosphorescence. The display of black is clearly de-
picted by controlling each element not to emit light, thereby
achieving a high contrast ratio. Even in a high performance
model, the contrast ratio of a liquid crystal monitor is roughly
1000:1, compared to that of an organic EL monitor which
achieves 250,000:1. It can be said to be the most suitable dis-
play monitor for diagnostic ultrasound systems.

3. Seamless Workflow

3.1 Operating console

During an ultrasound examination, the examiner applies
the transducer to the patient with one hand whilst manipu-
lating the operating console with the other, and at the same
time, observing ultrasound images displayed on the monitor.
To stay focused on the examination, it is desirable not to
take your eyes away from the monitor. An example of a rou-
tine examination that requires continuous operation is Dop-
pler waveform measurement. Firstly, on the real-time image,
the position of the Doppler sample gate is adjusted using the
"trackball (hereinafter referred to as T.B.)", and secondly,
when the desired image is obtained, the "Update" switch is
pressed to start the Doppler scanning. The "Freeze" switch
is pressed to stop updating, and finally, the "Store" switch
is used to record the image. If it is necessary to look away
from the monitor during the examination to check the loca-

Figure 10: “eFocusing” Off (left) and On (right)

Figure 11: Image suited to qualitative diagnosis (left) and image suited to morphological diagnosis (right)
tion of the various switches, the scanning plane can easily shift, and good Doppler waveforms may not be obtained. To avoid such errors with LISENDO 880, the area around the palm rest is designated as the home position, with the “T.B.,” “Update,” “Freeze & Gain,” and “Store” switches positioned so that the user can obtain the Doppler waveform with the palm of his hand fixed, without the need to look down (Figure 12 (a)). By ensuring the depth of the palm rest, twisting of the wrist can be reduced when the palm is fixed on the home position, such as when measuring Doppler waveforms as described above (Figure 12 (a)).

In LISENDO 880, the “L” and “R” switches have been added to “Enter” and “Undo” to be also operable with the palm resting in the home position (Figure 12 (b)). With an increasing number of short-cuts added, complicated functions such as Cardiac 3D and cardiac function analysis, increasingly used in routine examinations, will be made easier and more intuitive.

Moreover, in cardiovascular ultrasound, the frequently-used Time Gain Control (TGC) has been positioned on the lower left side of the operating console (Figure 12 (b)) for the first time in a Hitachi product. The arrangement of the frequently used B Gain and TGC in the front, combined with the easy-to-access position of the operating console, streamline workflow during the examination.

3.2 Automatic setting of the Doppler sample gate

The setting of a sample gate for Doppler measurement requires the examiner to operate the T.B. while applying the transducer to the patient. To reduce the burden, an automatic function to set the sample gate position has been developed.

Firstly, the system performs image recognition of the B-mode to determine the type of the section that is being displayed. Next, on the same image, it automatically estimates the position of the sample gate. The automation of these tasks has been made possible through machine learning techniques where a large number of images and gate positions set by technologists have been collected and analyzed by the algorithms of machine learning to create a database. This is incorporated into the system and referenced as needed to perform the automatic setting (Figure 13). The use of machine learning is intended to improve accuracy and versatility, automatically selecting the same sample gate position as the examiner would do manually.

This function performs the recognition process in transition to Doppler mode and allows the sample gate to be automatically set in the left ventricular inflow tract. In Dual Gate Doppler mode, furthermore, the sample gate for Tissue Doppler Imaging (TDI) is automatically set in the wall adjacent to the left ventricular annulus as well (Figure 14). This function should popularize the usage of Dual Gate Doppler, which, although of clinical benefit, involves the complicated procedure of setting sample gates in two different locations.

3.3 Automatic detection of end-diastole (Ed) and end-systole (Es)

In Simpson’s measurement and others, analysis using B-mode images obtained in end-diastole (Ed) and end-systole (Es) are an essential part of the routine examination. LISENDO 880 automatically detects Ed (R wave) and Es (T-wave end) by analyzing the ECG signals when the “Freeze” is selected and instantaneously displays images at
these phases side by side in dual screen mode (Figure 15). This functionality significantly reduces examination time removing the need to search for Ed and Es frames when using measurements such as Simpson’s method.

3.4 Automated Cardiac Measurement

Automation of measurements such as heart function measurement, Simpson’s measurement (Disc method in the LV, LA, and RA), FAC measurement, Teichholz measurement, and LA/AO (M-mode) measurement has made the examination more efficient. Conventionally, these measurements involve a cumbersome number of tasks that include image (phase) selection, measurement cursor setting, and trace line setting, increasing the challenge of quantification. The measurement cursor is automatically set in an optimal position by an automatic recognition process similar to the automatic setting of the Doppler sample gate described earlier (Figure 13).

In Simpson’s measurement, B-mode images in Ed and Es obtained by the above-mentioned automatic Ed/Es detection are displayed on the screen side by side, and the endocardial lining is traced by the same function, resulting in a great synergistic effect (Figure 15).

4. Your Application

4.1 VFM (Vector Flow Mapping)

It is predicted that myocardial wall motion causes complicated hemodynamics in the heart chambers, such as turbulence and vortices, that has an effect on systematic hemodynamics, myocardial walls, and so on. To date, this phenomenon has only been assessed from the myocardial wall motion as visualized by conventional Color Doppler and B-mode imaging. VFM is a technology that visualizes hemodynamics taking into consideration myocardial wall motion, and facilitating evaluation of blood flow functions. It can provide displays of Shear Stress on the cardiac wall and Relative Pressures in the heart chamber (Figure 16). VFM requires high temporal resolution for Color Doppler analysis, and therefore in conventional systems, the VFM images display poorer spatial resolution than those used in the routine examination because priority is given to temporal resolution. This has hampered the adoption of VFM analysis. The “HI Framerate” capability of LISENDO 880 strikes a balance between high spatial resolution and high temporal resolution in Color Doppler imaging, allowing VFM analysis to have the same feel as the routine examination. What can be expected in the future includes a new perspective on cardiac evaluation, such as the use of the Energy Loss function in the prognosis of heart failure, and clinical usefulness of the relative pressure difference, which changes with deteriorating left ventricular function.

4.2 Heart failure diagnostic package (VFM, Dual Gate Doppler and R-R Navigation)

With the current globally aging population, the incidence of heart failure is increasing. As roughly half of the patients will have atrial fibrillation (AF) and the other half have heart failure with a preserved ejection fraction (HFpEF) where the left ventricular ejection fraction (LVEF) is preserved, patients with AF and HFpEF are also on the rise.

In patients with HFpEF, a diagnostic index that replaces LVEF is required. LISENDO 880 comes equipped with VFM, a function capable of visualizing hemodynamics as described in section 4.1. Intracardiac hemodynamics are expected to stagnate in patients with a myocardial wall abnormality. In such a case, the heart muscle acting as a pump responds by bringing hemodynamics back to normal with the resultant overload on the myocardium. This overload results in decreased myocardial motion and leads to heart failure. VFM can capture early changes in the hemodynamics by Energy loss, Relative pressure, and other parameters.

What can be expected from this capability is that a cardiac overload can be predicted based on the hemodynamic state even in the case of diastolic heart failure.

In the case of atrial fibrillation, on the other hand, measurements should be made in the correct phase to factor in the effect of coexisting arrhythmia. Especially in the case of HFpEF in which the possibility of congenital heart disease is excluded, diastolic function index E/e’ is crucial in determining whether or not it is treatable. LISENDO 880 is equipped with R-R Navigation – a function that can instanta-
neously search out a phase in which the R-R interval is the same as in the previous 2 waveforms – to help as a navigator in determining the correct phase in the event of arrhythmia. Furthermore, it is not always possible to obtain the optimal phase because in Doppler mode the optimal heart rate is determined from a spectrum of several heart beats, although B-mode images can provide abundant information on heart rate that is used by the navigator for phase determination. In such a case, the combined use with Dual Gate Doppler is expected to be beneficial so that the left ventricular inflow velocity waveform obtained by PW mode and the left ventricular annulus velocity waveform obtained TDI PW mode can be displayed in the same phase to calculate E/e’ (Figure 17)

5. Ergonomic design

5.1 System design to prevent Visual Display Terminals (VDT) syndrome

In ultrasound examinations, the operator applies the transducer to the patient with one hand and manipulates the operating console with the other while observing the ultrasound images displayed on the monitor. Depending on the region being examined or the examination environment, the examiner often needs to twist his body position in an unnatural way during the examination which can place a large physical burden on him. LISENDO 880 has been designed with a focus on reducing the burden on the examiner’s neck and shoulders to prevent VDT syndrome. The console panel arm and monitor arm have a large range of motion to allow the examiner to maintain the optimal working posture either in the seated or standing position (Figures 18 (a) and 18 (b)).

- Operating console: Moves up and down by 700-1000 mm and swivels by 25 degrees
- Monitor: Moves up and down by 172 mm, swivels 360 degrees, and slides back and forth by 224 mm

As a result, the line of sight in the seated position falls about 10 degrees below the horizontal, as recommended by the Japan Society of Ultrasonics in Medicine. Furthermore, another joint is added to the monitor arm so that the monitor can move smoothly back and forth in parallel to make it easy to adjust to the optimal distance for each examiner (Figure 18(c)). Although such measures would be likely to increase the size of the system, a compact body size is realized as well.

5.2 Cable management

Challenges in the design of the body of the diagnostic ultrasound system include measures against VDT syndrome and improved management of transducer cables. In conventional models, transducer cables can get entangled whenever the examiner switches transducers during or between examinations.

LISENDO 880 has multiple side hooks on both sides of the operating console, one dedicated to each probe holder. The side hook is designed for the cable to be rolled up in a way such that when the probe is held in the holder the direction of the cable is horizontal to the direction in which the transducer is removed from the holder (Figure 19 (a)). As a result, when removed, the cable does not easily get entangled with the cable of other transducers. (Figure 19 (b)).

Consideration has also been given to the form, material and processing so that the cable can be pulled out smoothly, but is also held securely on the hook.

To be easily located, the hooks are designed to protrude from the sides of the console, at an angle against the root

Figure 17: Combined use of R-R Navigation and Dual Gate Doppler

Figure 18: Range of motion of the operating console and monitor
of the cable so that it is easily pulled out through the hook. They are also designed to retract under the console with a single touch so they can be folded away when the system is used in a small examination room or being moved to another place. Even in the retracted position, the hooks are designed to allow cables to be pulled out smoothly or held firmly (Figure 19 (c)).

Figure 19: Cable management

6. Conclusion

“LISENDO 880” provides more accurate “understanding of hemodynamics,” the basis of cardiovascular evaluation. With detailed analysis, it also provides information on the “efficient motion and pressure distribution of blood flow,” which has not been possible to investigate in the past. For all to live in safety and security in a society filled with smiles, we move forward with innovation in healthcare global team work.

*1 LISENDO, *2 Prosound, and *3 ARIETTA are registered trademarks of Hitachi, Ltd.

References