Distributed Cloud-based Ultrasound Platform: Innovative Pathway to Develop Ultrasound Imaging System

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Abstract: The current medical ultrasound imaging device is mainly divided into console ultrasound device and portable ultrasound device. In this article, a new concept along with an innovative pathway to develop ultrasound imaging devices, namely distributed cloud-based ultrasound system (DCUS), was proposed. In DCUS, the ultrasound probes from multiple terminals are used to complete the transmission and reception as well as analog-to-digital conversion of ultrasonic signals, and upload the original radio frequency (RF) signals or in-phase and quadrature (IQ) signals to the cloud server through ultra-bandwidth high-speed communication technology, while the centralized cloud server platform finishes processing of ultrasonic signals and transmits and distributes ultrasound imaging to each related terminal in real time. Various artificial intelligence (AI) algorithms can also be deployed on the cloud-based platform to achieve AI-powered imaging optimization, protocol standardization, and assisted diagnosis. Thus, by utilizing new cloud-based platform and super-high transmission technology and combining the advantages of console ultrasound and portable ultrasound systems with flexibility, high imaging quality and intelligent features, DCUS could become whole new ultrasound system for medical imaging applications in foreseeable future.

Key words: Ultrasound device; Portable ultrasound; Radio frequency signal; High-speed communication; Cloud server

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Medical ultrasound has a wide range of clinical applications within superficial structures, abdominal organs, obstetrics and gynecology, and cardiovascular systems. Because of its unique features such as real-time imaging, non-radiation, portable and cost-effective, ultrasound examination plays an indispensable role in many medical imaging modalities. Currently, medical ultrasound imaging devices are divided into two main forms: traditional console ultrasound and the newly developed portable ultrasound systems. Portable ultrasound can be further divided into laptop-based and pocket-sized styles according to its size and weight.

Advances in microelectronics and communication technologies have facilitated progress and evolution in

developing ultrasound imaging systems. Conventional console ultrasound instruments could be installed with sophisticated software and imaging package to provide superior imaging quality with more diagnostic functions, such as elastography, viscoelastic imaging, and contrast-enhanced ultrasound mode. At the same time, these technological developments have also been incorporated into portable ultrasound devices, which has led to rapidly increase the popularity of ultrasound applications, expanding the uses from ultrasound doctors in traditional imaging department to specialties physicians in clinical departments and even gradually into the healthcare at home.

With the rapid development of very large-scale integrated circuit, nanochip, ultrahigh bandwidth and

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ultrahigh-speed communication technologies, what new opportunities can these advancements bring to the research and development of future ultrasound imaging device? In this article, a new concept along with an innovative pathway to develop ultrasound imaging devices, namely distributed cloud-based ultrasound system (DCUS), was proposed and discussed.

Past and Current Diagnostic Ultrasound Devices

As early as in 1947, Karl Theodore Dussik, an Austrian neurologist and psychiatrist, developed an instrument that used ultrasound to create images of the brain. However, it was not until 1963 that the beginning of the most popular design of ultrasound scanners was ushered in, when the first hand-held compound contact B-Mode scanner was commercially available in the United States [1]. Following this, Walter Krause and Richard Soldner invented the real-time ultrasound scanner in 1965, and Siemens began producing the world's first real-time ultrasound system under the name Vidoson in 1967 [1,2]. Around 1983, real-time color Doppler ultrasound imaging scanner was produced by Aloka in Japan [3,4].

In the late 1970s and early 1980s, attempts were made to miniaturize ultrasound scanners so that they could be used in emergency, bedside, field, and remote areas [5]. Over the past years, portable ultrasound devices have now become another form of ultrasound equipment relative to the standard console ultrasound devices. More recently, portable ultrasound devices have now evolved from laptop-based to pocket-sized instruments, enabling burden-free portability and ready access to use (Fig. 1)[6]. There are many types of small ultrasound device developed by ultrasound companies worldwide and commercially available for clinical practice. From ACUSON P10 (Siemens Healthcare Ultrasound, Mountain View, CA, U.S.), the pioneer of pocket ultrasound device, to the latest newcomer Butterfly iQ (Butterfly Network, Inc., Milford, CT, U.S.), these portable ultrasound devices are equipped with new technologies such as capacitive micromachined ultrasonic transducer (CMUT), cloud-sharing and teleguidance technology, which expand the capabilities of clinical applications [2,7,8]. However, there are many technical limitations of portable ultrasound systems including lack of multimodal imaging capabilities and suboptimal spatial and temporal resolution, which cannot provide high quality or complete diagnostic examination as done with the standard console ultrasound devices [9-12]. On other hand, the high-end console ultrasound systems with high price tag could restrict its distribution and availability within the variable hospital and

professional services. In addition, upgrades of system and software may be limited by device mode and hardware of the platform. To cope with the era of digital and virtual environment, ultrasound system and platform with new concept should be explored and developed with use of advanced technologies.

Figure 1 Current typical diagnostic ultrasound devices: console ultrasound device (A) and portable ultrasound device, the latter is subdivided into laptop-based (B) and pocket-sized (C).

Distributed Cloud-based Ultrasound: The New Style of Ultrasound Devices

Portable ultrasound device has both advantages of cost-effectiveness and easy portability and disadvantages of limited imaging quality and lack of multiple imaging modes, while console ultrasound device has the advantages of multimodal functions and high-resolution imaging, but is expensive and less accessible. It would be very interesting and exciting to develop a new ultrasound system which integrate both the advantages of portable and console ultrasound machines and counteract the both disadvantages. Here, we propose the new concept of distributed cloud-based ultrasound system (DCUS), which is an innovative pathway to develop ultrasound imaging device that are different from portable and console ultrasound instruments by integrating modern high-speed communication networks, artificial intelligence (AI) modulars, and cloud-based computing technologies.

Concept of DCUS

Specially-designed ultrasound transducer is a standalone device which is able to transmit and receive ultrasound signals and upload the original radio frequency (RF) signals to the centralized cloud-based server through ultra-bandwidth high-speed communication technology, and then the cloud-based server/platform completes the processing of ultrasonic signals and conveys the ultrasound imaging to each display terminal in real time. Multiple transducers can be used simultaneously to connect the centralized cloud-based system which can process and distribute the imaging to end-users' workstations. To our best knowledge, this is first time to propose this new concept of DCUS. In DCUS system, comprehensive algorithms and imaging processing are deployed on the centralized cloud-based server/platform, which provides powerful computing power to conduct ultrasound signal processing and imaging modules just as the traditional console ultrasound device does. Since multiple transducers can use in different regions and share same cloud-based imaging system, high quality and multimodal ultrasound imaging, such as high-resolution imaging, color Doppler, elastography and contrast-enhanced ultrasound, can be obtained while effectively reducing hardware costs. Thus, DCUS retains the advantages of high-end console ultrasound devices with excellent imaging quality and multiple imaging functionality, while meantime keep hold of the advantages of portable ultrasound devices with low cost, light weight, portability, and extensive use.

Key Technologies for DCUS

The goal of DCUS is to provides similar imaging quality and functionality as high-end console ultrasound while achieving de-hosting and miniaturization, i.e., each terminal requires only dedicated transducer and a display workstation, which requires the synergy of several key technologies.

Specially designed ultrasound probes

The ultrasound probes should not only meet the requirements of conventional transducers for the number of array elements and scanning lines, but also need to have the built-in signal processing unit for time gain compensation, analog-to-digital conversion, as well as the unit for outputting the original ultrasonic RF signals.

Ultra-high bandwidth high-speed transmission network

In DCUS, the ultrasound raw RF signals can be transmitted to the cloud-based server, as the signal processing center for software beamforming and subsequent imaging, instead of using hardware beamforming by the built-in microcontroller of traditional ultrasound equipment. Therefore, DCUS has extremely stringent requirements for the transmitting bandwidth and the speed of the network. Taking the 64-channel ultrasound transducer as an example, to upload the raw RF signal before beamforming requires a data transmitting rate of about 10-40 Gbps, which is clearly not achievable with conventional communication technologies.

Figure 2 A diagram demonstrates a concept of distributed cloud-based ultrasound device and system.

The rapid development of communication technologies, such as terahertz and light fidelity (LiFi) communication technologies [13,14], provides strong technical supports and potentials for DCUS. For example, recently, a 6G-oriented 360-430Ghz terahertz real-time wireless transmission experimental system has been successfully established, reaching a transmission rate of 100 / 200Gbps, which is 10-20 times higher than that of 5G network [15].

Software beamforming

The quality of ultrasound imaging largely depends on the merits of the beamforming algorithm. At present, more and more high-end ultrasound devices use software beamforming. However, software beamforming requires high bandwidth for transmission channels, which usually requires ultra-high-speed interconnect buses such as PCIe and SRIO, and is not applicable to common low and medium-speed interconnect protocols such as USB and WiFi. For DCUS, terahertz or LiFi networks can meet the bandwidth and transmission speed requirements of software beamforming algorithm. By applying advanced algorithms, software beamforming provides focus on both transmit and receive at every point in the image, yielding numerous and obvious benefits including dramatically improved spatial resolution, enhanced image uniformity, improved image quality at depth, and reduced imaging artifacts [16]. In traditional ultrasound devices, software beamforming is often limited by hardware resources, while in a computationally powerful cloud platform, such limitations will no longer exist.

In addition, based on the powerful computing capabilities of the centralized cloud server of DCUS, various AI algorithms can also be deployed on the cloud server to achieve AI-powered imaging optimization, protocol standardization, and assisted diagnosis (Fig. 2).

Application Scenarios for DCUS

By utilizing high computing power cloud-based server to process the raw RF signals for imaging, DCUS can provide high-quality multimodal ultrasound images and thus can be applied in tertiary and secondary hospitals to meet the needs of clinical practice, research and teaching activities in radiology department. DCUS can effectively reduce the cost of purchasing ultrasound equipment for hospitals, and its excellent portability allows it to be flexibly used in emergency departments, operating rooms, infectious diseases departments and other clinical departments, solving the problems of traditional console ultrasound, which occupies a large space, is hard to move, and is difficult to sterilize.

For primary care hospitals, standardized protocols and AI modules deployed in DCUS can provide auxiliary

diagnosis and teaching functions. For primary care physicians who lack imaging experience and training, these protocols and AI modules can offer useful support during ultrasound examinations. DCUS can also be applied to the emergency ambulance system, which not only allows for high-quality ultrasound imaging at the emergency site, but also allows for remote technical assistance from the emergency center through the cloud-based platform. In primary care hospitals in remote areas or in emergency vehicles, the bandwidth and transmission speed may be limited. In this case, the original RF signal can be converted into an IQ signal and then uploaded to the cloud server. The IQ signal has a smaller data volume and thus requires less bandwidth although this will inevitably reduce the quality of ultrasound imaging.

Conclusions

This article presents the new concept and key technologies of DCUS. The DCUS retains the advantages of high-end console ultrasound devices while ensuring the portability, and can provide platform support for AI modules, thus promising to be the alternative ultrasound imaging device format that different from portable and console ultrasound systems. At present, ultra-bandwidth high-speed communication technology is developing rapidly, thus DCUS may become a reality in the foreseeable future.

Conflict of Interest

Authors have no conflict of interest to declare.

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