A Mini Review of Technical Development in the Biomedical Instruments

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***Abstract*—The article describes various technical development issues in biomedical instruments such as ultrasound, optics, positron tomography, magnetic resonance imaging, computed tomography, and other modalities. A brief description of the currently developed techniques from signal processing, electronics, and systems in biomedical instruments has been described at the pre-clinical levels. Therefore, academic researchers can learn about unwanted technical issues before optimizing the performance of electronic or system components in biomedical instrument applications.**

Keywords—Ultrasound; Positron Emission Tomography; Optics; X-ray; Computed tomography; THz wave; THz optics

I. Introduction

Traditional biomedical instruments in the academic fields are X-ray, ultrasound, optics, computed tomography, and magnetic resonance imaging modalities which are widely used in pre-clinical situations [1-6]. In the current technical purposes, several performances such as resolution, data transfer capability, noises, thermal issues, noises, and sizes will be considered because of several problems in human diseases [7-12]. In addition, several electronic components such as ultra-high speed analog-digital data converter cards, parallel central processing units, and high voltage power supplies could improve various performance merits in biomedical instrument applications [13-16].

Traditional biomedical instruments also have a variety of combination types so we call photo-acoustic instruments which are composed of ultrasonic and optical systems, magnetic resonance imaging-guided high-intensity focused ultrasound instruments which are composed of a magnetic system with temperature sensor and treatment ultrasound system, and ultrasound-guided optical instruments [17-20]. Currently, these combinational biomedical instruments could provide some beneficial disease information that cannot be shown the traditional biomedical instruments. In the photo-acoustic instruments, the physiological and structural tissue information could be simultaneously provided to users [21-24]. However, ultrasound only provides structural information from human tissues or organs such as skin, eyes, and hair [25-28]. The magnetic resonance imaging-guided intensity-focused ultrasound instrument can provide temperature information of the target diseases but the ultrasound cannot provide the temperature data in the target [29-32]. Compared to traditional biomedical instruments, these combinational biomedical instruments could provide other beneficial information data to users [33-36].

The next section describes the concept and related technical development of the ultrasound, optics, x-ray and computed tomography, and other biomedical instruments. The last section is the total summary of this mini review article to show the technical development guidelines for such biomedical instruments.

II. Ultrasound

The current research trend of the securities, electronics, transducers, and signal processing methods in ultrasound instruments is briefly introduced here.

The portable ultrasound imaging system can be used in ambulances or sports games due to convenient usage without a power cord because the portable battery can provide power [37-40]. In addition, the portable photo-acoustic system is also used in small clinics [41-44]. Nowadays, the security of the portable ultrasound machine is highly concerned due to patient issues so various signal processing techniques have been used [45-49]. This is because the image or text data of the patients in the portable acoustic systems need to be transferred through secure internal or external network devices such as LAN or Wi-Fi [50-55].

The performance enhancement of the transducer or electronic components in the ultrasound and photo-acoustic instruments has been developed [56-59]. The microbeam stimulation has been developed due to potential applications in the brain diseases [60-63]. High-speed converters or switches in the ultrasound system integrated circuits have been developed for array transducer or fast-switching ultrasound applications because the semiconductor industry could provide a very small-size fabrication process [64-68]. For example, in the biopsy needle devices, the switches are useful for array devices [69, 70].

The transmitter in the ultrasound system is one of the most crucial components and there are several analog electronics or digital signal processing methods to improve the sensitivity or bandwidth optimization [71-76]. In the transmitter, the pulser or power amplifier is a kind of analog component such that the output voltage or power, bandwidth, linearity, and noise are the most important parameters at the circuit design level [77-84]. Therefore, several circuit techniques boosting the performances of the power amplifier have been developed [85-90]. Such power amplifier performances are very important to obtain proper tissue information or appropriate stimulation amplitudes [91, 92]. Nonlinear power amplifiers have been developed to reduce the power consumption in portable ultrasound systems [93-98]. Similarly, the receiver in the ultrasound system is used to filter and amplify the echo signals such that the sensitivity, bandwidth, and noise characteristics are the most important parameters [99-104].

In high-frequency (> 15 MHz) very-high-frequency (> 100 MHz), and ultra-high frequency (> 200 MHz) ultrasound applications such as tumor stimulations at cellular levels, the transmitter or transducer performances are very critical because the target sizes are very smaller than 1 um [105-110]. However, the acoustic stimulation methods triggered by the ultrasound transducers are useful to trap and treat the cells such that electronics or system developments have been performed [111, 112]. Therefore, academic researchers want to use these sensitive ultrasound systems even though they are very expensive and noise-sensitive.

The measurement instruments or signal processing techniques for ultrasound transducers and electronics have been developed for accurate characteristics [113-119]. The optics and ultrasound measurement system integrated with highly focused or ultra-wide optical lens has been developed to use both highly penetrated and high spatial resolution characteristics [120-123]. For surgical or operational purposes, ultrasound instruments are widely used for stimulation applications [124-127].

III. OPTICS

The optical system has been used in the photoacoustic system such that there are several optical systems or lenses have been developed [128-133]. Due to light characteristics, eye imaging areas are highly used for pre-clinical and clinical purposes [134-137]. For example, microscopic areas require highly demanding optical resolutions that are less than 0.1 um such that there are several different types of optical lens systems to optimize the optical resolutions [138-141]. In microscopic fields, several techniques such as focal length or field of view correction [142-145]. Mathematical analysis or correction methods even at the software level are used to improve the optical system performances such that it is useful to estimate the performances of the medical instruments because the optical lens affects the performance of the light in the desired target [146-149].

In addition, terahertz optical imaging methods have been developed in the security and medical imaging areas due to the specific transparent characteristics of water in the tissues [150-153]. To enhance imaging performances in such terahertz optical areas, tolerance or signal optimization techniques are widely used [154-157]. In addition, several machines or deep learning-supported methods at the software levels are widely used to increase the accuracy parameters of the data classification in biomedical instruments such as skin, eye, and implant applications [158-167]. Head-mounted displays have been combined with pre-clinical or medical applications such that several off-axis lenses are developed for surgical operations, inspection, or educational purposes [168-173]. Therefore, several companies such as Apple, Samsung, Microsoft, and Meta have been commercialized with appropriate prices and applications. However, medical imaging modalities have been recently highlighted such that there are very small numbers of applications in the market.

IV. X-RAYS, COMPUTED TOMOGRAPHY, AND OTHERS

The current research direction of X-ray or computed tomography or other signal or imaging biomedical instruments at the electronics or system level is that the development of their imaging performances is a concern. For example, brain-computer interface systems have been widely developed due to semiconductor circuit development and deep learning processing techniques [174-180]. In the brain-computer interface system, several classification techniques have been developed with machine and deep learning techniques to improve data accuracy [181]. Detector sensors or electronics in positron emission tomography have been developed [182-186]. The X-ray detector electronics also have been developed to improve the sensitivity to easily recognize the tissue information near the bone in humans or animals [187, 188]. This is because imaging techniques in biomedical instruments are useful to improve the final image quality [189, 190]. For in-vivo, nano-pore, DNA, or retinal applications, circuit or system sensitivity or noise reduction techniques are widely used to increase the sensitivity performances [191-196].

V. CONCLUSION

Technical issues in the biomedical instruments have been briefly introduced with description and technology information. Due to several parameter constraints such as sensitivity, bandwidth, penetration depth, noise, heat issues, and size, the performances of the biomedical instruments cannot be optimized. Therefore, academic researchers tried to use some trade-off relationships depending on the specific applications. Therefore, this review article could be beneficial for the electronics or system developers to consider some constraints before developing such biomedical instruments because all the highest performances cannot be achieved together.

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