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Optoacoustic Instrument Systems – A Mini Review

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***Abstract*—Optoacoustic instrument systems have been widely developed due to the mutual advantages of the optical and acoustic properties. Recently, optical and acoustic system developments composed of optoacoustic instrument systems have been widely focused on overcoming the limitations of various applications. However, most of the review articles for optoacoustic instruments are focused on how to handle and use optical or ultrasound systems. This article is intended to introduce how to design and use each optical and ultrasound device components that construct the optoacoustic instrument systems Therefore, a technical summary of the optoacoustic instrument systems at the device and component level could be helpful to academic researchers or engineers who construct such optoacoustic instrument systems.**

Keywords— optoacoustic instrument systems; optical systems; acoustic systems

I. Introduction

Imaging modalities for human disease diagnosis have been widely developed in clinics or hospitals [1-12]. It is because they are beneficial to determine the surgery operation or treatment using medicines [13-18]. There are several imaging modalities such as magnetic resonance imaging (MRI), computed tomography (CT), ultrasound, positron emission tomography (PET), and optical imaging [19-25]. The transmit sources of these modalities are light, magnetics, mechanical vibration, radiation, etc [26-28]. The imaging modalities have their advantages and limitations so the current research direction of the imaging modalities [29-34]. They are combinational modalities such as MRI-guided high-intensity focused ultrasound (HIFU), PET-CT, Optoacoustic instrument system, and PET-MRI [35-38].

The fundamental principle of signal generation from an optoacoustic instrument system [39-42]. The optoacoustic instrument systems are composed of optical and acoustic (ultrasonic or ultrasound) systems [43, 44].

The fundamental concept of the optoacoustic instrument systems is to use the transmit sources of light and receive sources of the transducer devices in the receive sources [45]. The transmit sources such as laser, light emitting diode (LED), or radio frequency (RF) power sources would be delivered to generate the thermal expansion into the desired targets such as human tissues or cells. Typically, RF power sources are not used to construct optoacoustic systems due to very low sensitivity [46].

The mechanical vibration caused by thermal expansion generates acoustic waves from the target. In the receiver systems, the ultrasound transducers need to detect such very weak waves [47-50]. The detected waveforms are amplified by a preamplifier and time-gain compensation amplifier and then, are digitized using an analog-to-digital converter (ADC) in data acquisition systems before creating the images [51-54]. From the obtained images, we could obtain the necessary information about the desired target for human disease diagnosis [55-62].

The optoacoustic instrument systems utilize mutual advantages of the optical and acoustic properties to overcome such limitations of each modality. The advantages of the optical systems could provide the tissue characteristics because absorbed light properties are different for each different light wavelength [63]. Thus, they could provide high image contrast for different tissues [64-68]. The advantages of the acoustic properties are non-invasive and less harmful sources and high spatial resolutions [69-71]. Therefore, optical or acoustic-only systems could provide only one advantage compared to optoacoustic instrument systems.

As mentioned in the theory of the optoacoustic process, we could understand how to make and combine the optical system and ultrasound system. From currently published review papers, these optical or ultrasound system-based optoacoustic systems do not show in detail how to construct the optical system components or how to utilize them so optical design engineers in optoacoustic instrument systems do not have enough information for system optimization. In addition, most review articles of the optoacoustic instrument systems just describe how to use such a system for specific biomedical applications so this review article could be helpful for the researchers who design and construct the optical and acoustic systems used in optoacoustic instrument systems.

Sections II and III describe which kinds of optical and acoustic systems are used to construct optoacoustic instrument systems, respectively, and which components should be utilized. Section IV describes the optoacoustic instrument systems, design techniques, and other related component design including commercially available optoacoustic instrument system information. Section V is the summary of the article.

II. Optical Systems

The optical systems are very important in how to effectively generate light sources [72-76]. The convex, conical, or concave optical lens (optical systems) have been normally used to diverge or focus the light beam into the target [77-80]. Depending on the target locations, these types of optical lenses were combined to deliver the light beam. The light beam was worked by the transmit electronics of drivers and optical amplifiers with proper repetition time.

Recently, micro-optical systems were used to focus the beams that increase the beam intensity [81-83]. The fisheye optical systems were used to overcome the small target fields [84-86]. The designed fisheye optical system could scan the target in wide diagonal and vertical locations. This could be helpful to decrease motor scanning ranges, thus reducing unnecessary motor noises because motor noises critically affect the image quality.

The macro optical systems are useful for the low-sensitivity optoacoustic instrument systems because they could improve the very low intensity of the light sources [87-89]. Therefore, the engineers could construct small-size portable systems by using macro optical systems.

The double-gauss optical systems are effective in delivering the light beam with a constant beam shape [90-93]. The uniform field of view of the target area could help reduce the signal intensity variances. Therefore, it could compensate for the burden of the receiver electronics.

The omnidirectional optical systems are useful to cover wide target ranges with uniform intensities. Original omnidirectional optical lenses are used to cover 360^{o} in field of view [94-96]. However, this designed optical system could cover 180^{o} area in optoacoustic instrument systems.

The specific optical systems that cover several light wavelengths are useful for optoacoustic instrument systems because each different characteristic is dependent on the tissue light absorption rate. For instance, water, melanin, hemoglobin, collagen, and DNA have different absorption rates of the light beam. The custom-made optical systems that combine three different lights such as green, red, and blue lights are suitable to generate only one light source [97-100]. However, the received acoustic signals in the signal processing steps need to be differentiated for each different light wavelength to obtain specific tissue information [101-104].

III. Acoustic Systems

Acoustic systems are composed of transducer devices and their supporting hardware with algorithms [105-110]. Compared to ultrasound-only systems, the acoustic systems used in optoacoustic instrument systems are receiver electronics of the ultrasound systems with synchronizing electronics that need to be compatible with optical systems [111-113]. Therefore, protection circuits and transmit control electronics used in ultrasound systems are not necessary to be implemented [114]. Compared to ultrasound-only systems, optical systems generate lower acoustic powers so the receiver electronics need to have larger voltage gains for image mapping [115-118]. Therefore, high voltage gains in the receivers normally increase the noise levels [119-121]. This could be a large burden for electronics engineers due to lowering the signal-to-noise ratio [122-125]. In addition, the acoustic signals generated by light sources normally produce unwanted high-frequency noise signals with higher signal distortions [126-131]. Therefore, engineers need to be concerned about the signal identity to detect the right signals.

Timing algorithms between the transmit electronics for light generation and the receive electronics for acoustic signal reception need to be concern [132-136]. Typically, a lower pulse repetition rate (PRF) needs to be controlled so the light generation timing and acoustic signal reception need to be covered.

In particular, matching circuit units are needed to deliver the optimized power to the transducer while reducing the radiation effects [137-139]. Between ultrasound transducers and receiver electronics, matching circuit units are necessary for very weak acoustic signal levels, especially for optoacoustic instrument systems [140-142]. There are some passive components such as resistors, capacitors, and inductors which make matching circuits [143-146]. Therefore, resonant frequency shifts and electrical impedance values need to be properly adjusted [147]. Without matching circuit units, the desired power could be reduced up to one or fourth times [148-151]. This could be very critical for high-frequency receiver systems.

For optoacoustic instrument systems, different types of ultrasound transducers could be used such as a ring or circular-type transducers. These types of transducers could be easily detected by the optically triggered acoustic signals. However, transducer fabrication costs could be increased. For traditional transducers used in ultrasound systems, mechanical motors that move transducers need to be controlled by step motors [152-159]. Therefore, this configuration could affect the signal-to-noise ratio of the optoacoustic instrument systems.

IV. OPTOACOUSTIC INSTRUMENT SYSTEMS

The optoacoustic instrument systems are composed of optical and acoustic systems with timing control logic and software algorithms [160]. The first optoacoustic instrument system was produced Vevo LAZR X by Fujifilm VISUALSONICS Inc. located in Canada. PST Inc. also made PAFT for small animal imaging. iTheraMedical GmbH made MSOT inVision for real-time body imaging applications. Endra Life Sciences made the Nexus 128 + for tumor imaging. Tomowave Inc. fabricated LOUISA for breast cancer imaging applications. The transmit source in these optoacoustic instrument systems is a laser.

However, the next two systems utilizing LED sources are transmit sources. In the optoacoustic instrument system manufacturer located in Japan, Cyberdyne Corp. which produces Acoustic X using LED array, and Advantest Corp. manufactured Hadatomo Z Photoacoustic Microscope WEL 5200 based on laser sources. However, these commercial instrument systems are still tested for clinical purposes and they are currently not used for diagnosis purposes in clinics or hospitals because some alternating imaging instrument systems cover the advantages of the systems. Breast cancer imaging applications might be one of the solutions for optoacoustic instrument systems.

To fully commercialize the optoacoustic instrument systems, full custom level design of the optoacoustic instrument systems requires optical and ultrasound engineers collaborating on the system level design. First of all, the whole system specifications such as noise level, lateral and axial resolutions, signal-to-noise ratio, dynamic signal level, etc need to be determined [161-164].

Second, the most important device components need to be properly selected or designed such as laser, power amplifier, transducer, analog-to-digital converter, storage space, and signal processing units depending on the budget and whole system specifications [165-168].

Third, software algorithms and user interface need to be determined. Last, is the system interface such as testing environment devices (water tank, transducer connector electronics, laser cooling systems, etc) [169-171]. The multi-axis supported tilt, angular, and motion stages in the pulse-echo measurement system need to be constructed with a water tank, target plates, and transducer holder [172-177].

V. CONCLUSION

This article is the technology summary of the optoacoustic instrument systems especially used for medical instrument applications. There are a variety of medical instruments used in small clinics or large hospitals even in low-income countries. Among those medical instruments, newly focused medical imaging instruments just like optoacoustic instrument systems were described with fundamental principles for academic readers or engineers.

Due to recent semiconductor, communication, and software technology developments, various medical instruments are becoming more popular and compact [178]. Even though some fundamental medical instruments were developed earlier than 1950, they are not widely used due to hardware and software technology limitations. In addition, there are deep-learning and security techniques for medical imaging modalities [179, 180].

For example, the fundamental concept of the optoacoustic instrument systems was first developed around 1900. With recently developed technology, these medical instruments are becoming compact and complex. In addition, researchers in academic areas engineers in companies, or doctors in hospitals could find some useful applications. Investigating research-related data to develop the optoacoustic device hardware and ultrasonic transducers and presenting guidelines for designing and manufacturing optical devices could be helpful to optical or ultrasound device engineers or researchers to optimize the performances of the optoacoustic instrument systems.

Various optical systems such as double-gauss, fisheye, omnidirectional, microlens, etc have been developed to optimize the light beam quality because the received acoustic signal power is relatively low compared to ultrasound-only systems. The receiver electronics also need to be considered to improve the signal-to-noise ratio. Currently, developed optoacoustic instrument systems are only combinations of commercially available optical and ultrasound systems with some interface and algorithms. However, full custom-made optoacoustic instrument systems could improve the image quality while compensating the costs. The engineers could consider selecting the right devices or components to construct the instrument systems [174, 181-187]. Most optical design engineers do not have some experience as ultrasound system engineers. Therefore, they need to collaborate full custom design of the systems. This review article could be a guideline to understand how to select the right optical and ultrasound components and to design full custom-level instrument systems.

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REFERENCES

[1] B. H. Hasegawa, *The Physics of Medical X-ray Imaging, Or, The Photon and Me--how I Saw the Light*. Madison, WI, USA: Medical Physics Publishing, 1991.

[2] S. Ryu, J. Ryu, and H. Choi, "Fisheye lens design for solar-powered mobile ultrasound devices," *Technol. Health Care*, vol. 30, pp. 243-250, 2022.

[3] W. Abbasi, H. Choi, and J. Kim, "Hexagonal Stimulation Digital Controller Design and Verification for Wireless Subretinal Implant Device," *Sensors*, vol. 22, p. 2899, 2022.

[4] A. Wahle, G. P. M. Prause, S. C. DeJong, and M. Sonka, "Geometrically correct 3-D reconstruction of intravascular ultrasound images by fusion with biplane angiography-methods and validation," *IEEE Trans. Med. Imaging*, vol. 18, pp. 686-699, 1999.

[5] P. Lum, M. Greenstein, C. Grossman, and T. L. Szabo, "High-frequency membrane hydrophone," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, vol. 43, pp. 536-544, 1996.

[6] H. Riaz, J. Park, H. Choi, H. Kim, and J. Kim, "Deep and Densely Connected Networks for Classification of Diabetic Retinopathy," *Diagnostics*, vol. 10, p. 24, 2020.

[7] H. Wang, T. A. Ritter, W. Cao, and K. K. Shung, "Passive materials for high-frequency ultrasound transducers," in *Medical Imaging'99*, 1999, pp. 35-42.

[8] H. Choi, "Novel dual-resistor-diode limiter circuit structures for high-voltage reliable ultrasound receiver systems," *Technol. Health Care*, vol. 30, pp. 513-520, 2022.

[9] P. Sprawls, *Physical Principles of Medical Imaging*. Alphen aan den Rijn, Netherlands: Aspen Publishers, 1993.

[10] R. B. A. Zawawi, W. H. Abbasi, S.-H. Kim, H. Choi, and J. Kim, "Wide-Supply-Voltage-Range CMOS Bandgap Reference for In Vivo Wireless Power Telemetry," *Energies*, vol. 13, p. 2986, 2020.

[11] F. S. Foster, K. A. Harasiewicz, and M. D. Sherar, "A history of medical and biological imaging with polyvinylidene fluoride (PVDF) transducers," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, vol. 47, pp. 1363-1371, 2000.

[12] H. Choi, J. Park, and Y.-M. Yang, "A Novel Quick-Response Eigenface Analysis Scheme for Brain-Computer Interfaces," *Sensors*, vol. 22, p. 5860, 2022.

[13] J. Hong, Y. Oh, H. Choi, and J. Kim, "Low-Area Four-Channel Controlled Dielectric Breakdown System Design for Point-of-Care Applications," *Sensors*, vol. 22, p. 1895, 2022.

[14] H. Choi, X. Li, S.-T. Lau, C. Hu, Q. Zhou, and K. K. Shung, "Development of Integrated Preamplifier for High-Frequency Ultrasonic Transducers and Low-Power Handheld Receiver," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, vol. 58, pp. 2646-2658, 2011.

[15] S. Stergiopoulos, *Advanced Signal Processing Handbook: Theory and Implementation for Radar, Sonar, and Medical Imaging Real Time Systems*. Boca Raton, FL, USA: CRC press, 2000.

[16] K. S. Karim, P. Servati, N. Mohan, A. Nathan, and J. A. Rowlands, "VHDL-AMS modeling and simulation of a passive pixel sensor in a-Si: H technology for medical imaging," in *2001 IEEE International Symposium on Circuits and Systems*, Sydney, NSW, Australia, 2001, pp. 479-482.

[17] J. Kim, K. You, S.-H. Choe, and H. Choi, "Wireless Ultrasound Surgical System with Enhanced Power and Amplitude Performances," *Sensors*, vol. 20, p. 4165, 2020.

[18] L. Hoff, *Acoustic characterization of contrast agents for medical ultrasound imaging*. Berlin, Germany: Springer Science & Business Media, 2001.

[19] R. B. A. Zawawi, H. Choi, and J. Kim, "High PSRR Wide Supply Range Dual-Voltage Reference Circuit for Bio-Implantable Applications," *Electronics*, vol. 10, p. 2024, 2021.

[20] H. Choi, J. Park, and Y.-M. Yang, "Whitening Technique Based on Gram-Schmidt Orthogonalization for Motor Imagery Classification of Brain-Computer Interface Applications," *Sensors*, vol. 22, p. 6042, 2022.

[21] T. A. Ritter, T. R. Shrout, R. Tutwiler, and K. K. Shung, "A 30-MHz piezo-composite ultrasound array for medical imaging applications," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, vol. 49, pp. 217-230, 2002.

[22] H. Kang, H. Choi, and J. Kim, "Ambient Light Rejection Integrated Circuit for Autonomous Adaptation on a Sub-Retinal Prosthetic System," *Sensors*, vol. 21, p. 5638, 2021.

[23] W. R. Hendee and E. R. Ritenour, *Medical Imaging Physics*. Hoboken, NJ, USA: John Wiley & Sons, 2003.

[24] K. Kim and H. Choi, "A New Approach to Power Efficiency Improvement of Ultrasonic Transmitters via a Dynamic Bias Technique," *Sensors*, vol. 21, p. 2795, 2021.

[25] K. Tachibana and S. Tachibana, "Application of ultrasound energy as a new drug delivery system," *Jpn. J. Appl. Phys.*, vol. 38, p. 3014, 1999.

[26] M. N. Ullah, C. Park, E. Pratiwi, C. Kim, H. Choi, and J.-Y. Yeom, "A new positron-gamma discriminating phoswich detector based on wavelength discrimination (WLD)," *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 946, p. 162631, 2019.

[27] L. L. Lay, S. J. Carey, and J. V. Hatfield, "Pre-amplifier arrays for intra-oral ultrasound probe receiving electronics," in *IEEE Ultrason. Symp.*, 2004, pp. 1753-1756 Vol.3.

[28] M. Ullah, E. Pratiwi, J. Park, K. Lee, H. Choi, and J. Yeom, "Wavelength discrimination (WLD) TOF-PET detector with DOI information," *Phys. Med. Biol.*, vol. 65, p. 055003, 2019.

[29] L. Jian-yu and J. L. Waugaman, "Development of a linear power amplifier for high frame rate imaging system [biomedical ultrasound imaging applications]," in *IEEE Ultrason. Symp.*, 2004, pp. 1413-1416 Vol.2.

[30] R. B. A. Zawawi, H. Choi, and J. Kim, "High-PSRR Wide-Range Supply-Independent CMOS Voltage Reference for Retinal Prosthetic Systems," *Electronics*, vol. 9, p. 2028, 2020.

[31] K. Hynynen, "Demonstration of enhanced temperature elevation due to nonlinear propagation of focussed ultrasound in dog's thigh in vivo," *Ultrasound Med. Biol.*, vol. 13, pp. 85-91, 1987.

[32] J. Cheon, D. Lee, and H. Choi, "A CMOS Image Sensor with a Novel Passive Pixel Array and High Precision Current Amplifier for a Compact Digital X-ray Detector," *J. Med. Imaging. Health. Inf.*, vol. 10, pp. 2745-2753, 2020.

[33] F. J. Fry, "Intense Focused Ultrasound in Medicine," *Eur. Urol.*, vol. 23(suppl 1), pp. 2-7, 1993.

[34] K. K. Shung and G. A. Thieme, *Ultrasonic Scattering in Biological Tissues*. Boca Raton, FL, USA: CRC press, 1992.

[35] J. Kim, K. S. Kim, and H. Choi, "Development of a low-cost six-axis alignment instrument for flexible 2D and 3D ultrasonic probes," *Technol. Health Care*, vol. 29, pp. 77-84, 2021.

[36] S. S. Bhat, T. T. Fernandes, P. Poojar, M. da Silva Ferreira, P. C. Rao, M. C. Hanumantharaju, G. Ogbole, R. G. Nunes, and S. Geethanath, "Low-Field MRI of Stroke: Challenges and Opportunities," *J. Magn. Reson. Imaging*, vol. 54, pp. 372-390, 2021.

[37] C. Guy and D. Ffytche, *An introduction to the Principles of Medical Imaging*. London, United Kingdom: World Scientific Publishing Company, 2005.

[38] M. N. Ullah, Y. Park, G. B. Kim, C. Kim, C. Park, H. Choi, and J.-Y. Yeom, "Simultaneous Acquisition of Ultrasound and Gamma Signals with a Single-Channel Readout," *Sensors*, vol. 21, p. 1048, 2021.

[39] A. Fatima, K. Kratkiewicz, R. Manwar, M. Zafar, R. Zhang, B. Huang, N. Dadashzadeh, J. Xia, and K. M. Avanaki, "Review of cost reduction methods in photoacoustic computed tomography," *Photoacoustics*, vol. 15, p. 100137, 2019.

[40] H. Choi, Y. J. Ju, J. H. Jo, and J.-M. Ryu, "Chromatic aberration free reflective mirror-based optical system design for multispectral photoacoustic instruments," *Technol. Health Care*, vol. 27, pp. 397-406, 2019.

[41] L. V. Wang and H.-i. Wu, *Biomedical Optics: Principles and Imaging*. Hoboken, NJ, USA: John Wiley & Sons, 2012.

[42] J. Blitz and G. Simpson, *Ultrasonic Methods of Non-destructive Testing*. Berlin, Germany: Springer Science & Business Media, 1995.

[43] H. Choi, S. Kim, J. Kim, and J.-M. Ryu, "Development of an Omnidirectional Optical System Based Photoacoustic Instrumentation," *J. Med. Imaging Health Inf.*, vol. 8, pp. 20-27, 2018.

[44] H. Choi and J.-M. Ryu, "Photo-Acoustic Applications Using a Highly Focused Macro Lens," *J. Med. Imaging Health Inf.*, vol. 7, pp. 25-29, 2017.

[45] H. Choi, "Design of Preamplifier for Ultrasound Transducers," *Sensors*, vol. 24, p. 786, 2024.

[46] H. Choi and J. Ryu, "Telecentric Collimator Optical System Design for Photoacoustic System," *Journal of Mechanics in Medicine and Biology*, vol. 23, p. 2340106, 2023.

[47] Y. Zeng, J. Hao, J. Zhang, L. Jiang, S. Youn, G. Lu, D. Yan, H. Kang, Y. Sun, and K. K. Shung, "Manipulation and Mechanical Deformation of Leukemia Cells by High-Frequency Ultrasound Single Beam," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, vol. 69, pp. 1889-1897, 2022.

[48] J. Kidav and P. M. Pillai, "Design of a 128-channel transceiver hardware for medical ultrasound imaging systems," *IET Circuits Devices Syst.*, vol. 16, pp. 92-104, 2022.

[49] H. Choi and S.-H. Shin, "A Mathematically Generated Noise Technique for Ultrasound Systems," *Sensors*, vol. 22, p. 9709, 2022.

[50] S. Saitoh, T. Kobayashi, K. Harada, S. Shimanuki, and Y. Yamashita, "A 20 MHz single-element ultrasonic probe using 0.91 Pb (Zn/sub 1/3/Nb/sub 2/3/) O/sub 3/-0.09 PbTiO/sub 3/single crystal," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control* vol. 45, pp. 1071-1076, 1998.

[51] J. Kim, K. You, and H. Choi, "Post-Voltage-Boost Circuit-Supported Single-Ended Class-B Amplifier for Piezoelectric Transducer Applications," *Sensors*, vol. 20, p. 5412, 2020.

[52] H. Choi, "Stacked Transistor Bias Circuit of Class-B Amplifier for Portable Ultrasound Systems," *Sensors*, vol. 19, p. 5252, 2019.

[53] K. K. Shung, M. Smith, and B. M. Tsui, *Principles of Medical Imaging*. Cambridge, MA, USA: Academic Press, 2012.

[54] H. Choi, "An Inverse Class-E Power Amplifier for Ultrasound Transducer," *Sensors*, vol. 23, p. 3466, 2023.

[55] J. M. Cannata, J. A. Williams, Q. Zhou, T. A. Ritter, and K. K. Shung, "Development of a 35-MHz piezo-composite ultrasound array for medical imaging," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, vol. 53, pp. 224-236, 2006.

[56] S.-H. Shin, W. Sok Yoo, and H. Choi, "Development of modified RSA algorithm using fixed mersenne prime numbers for medical ultrasound imaging instrumentation," *Comput. Assisted Surg.*, vol. 24, pp. 73-78, 2019.

[57] I. Hrazdira, J. Škorpíková, and M. Dolníková, "Ultrasonically induced alterations of cultured tumour cells," *Eur. J. Ultrasound*, vol. 8, pp. 43-49, 1998.

[58] S.-H. Shin and H. Choi, "Image Formation Technique Using Advanced Matrix Pattern in Fourier Transform for Medical Ultrasound

Machine," *J. Med. Imaging. Health. Inf.*, vol. 9, pp. 1950-1954, 2019.

[59] S.-H. Shin, W.-S. Yoo, and H. Choi, "Development of Public Key Cryptographic Algorithm Using Matrix Pattern for Tele-Ultrasound Applications," *Mathematics*, vol. 7, p. 752, 2019.

[60] C. R. Hill, J. C. Bamber, and G. t. Haar, *Physical Principles of Medical Ultrasonics*. Hoboken, NJ, USA: Wiley Online Library, 2004.

[61] H. Choi, "Class-C Linearized Amplifier for Portable Ultrasound Instruments," *Sensors*, vol. 19, p. 898, 2019.

[62] J. A. Ketterling, O. Aristizabal, D. H. Turnbull, and F. L. Lizzi, "Design and fabrication of a 40-MHz annular array transducer," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, vol. 52, pp. 672-681, 2005.

[63] D. Jeon, J. Park, J. Ryu, and H. Choi, "Design of an Internal Focusing Tube Lens for Optical Inspection Systems," *Appl. Sci.*, vol. 14, p. 1518, 2024.

[64] F. Zheng, X. Zhang, C. T. Chiu, B. L. Zhou, K. K. Shung, H. F. Zhang, and S. Jiao, "Laser-scanning photoacoustic microscopy with ultrasonic phased array transducer," *Biomed. Opt. Express*, vol. 3, pp. 2694-2698, 2012.

[65] S.-W. Choe, K. Park, C. Park, J. Ryu, and H. Choi, "Combinational light emitting diode-high frequency focused ultrasound treatment for HeLa cell," *Comput. Assisted Surg.*, vol. 22, pp. 79-85, 2017.

[66] H. M. Spencer, J. M. Rodgers, and J. M. Hoffman, "Optical design of a panoramic, wide spectral band, infrared fisheye lens," in *Proc. Contract*, 2007, pp. 63421P-63421P-11.

[67] W. J. Smith, *Modern Optical Engineering*. New York, NY, USA: McGraw-Hill Education, 2007.

[68] T. Yu, Z. Wang, and S. Jiang, "Potentiation of cytotoxicity of adriamycin on human ovarian carcinoma cell line 3AO by low-level ultrasound," *Ultrasonics*, vol. 39, pp. 307-309, 2001.

[69] J. K. Poulsen, "Low loss wideband protection circuit for high frequency ultrasound," *IEEE Ultrason. Symp.*, vol. 1, pp. 823-826, Oct. 17-20 1999.

[70] H. Choi, "Class-C Pulsed Power Amplifier with Voltage Divider Integrated with High-Voltage Transistor and Switching Diodes for Handheld Ultrasound Instruments," *Energies*, vol. 15, p. 7836, 2022.

[71] F. Tranquart, N. Grenier, V. Eder, and L. Pourcelot, "Clinical use of ultrasound tissue harmonic imaging," *Ultrasound Med. Biol.*, vol. 25, pp. 889-894, 1999.

[72] H. Choi, J. Ryu, and C. Yoon, "Development of novel adjustable focus head mount display for concurrent image-guided treatment applications," *Comput. Assisted Surg.*, vol. 22, pp. 163-169, 2017.

[73] H. Choi and J. Ryu, "Design of Wide Angle and Large Aperture Optical System with Inner Focus for Compact System Camera Applications," *Appl. Sci.*, vol. 10, p. 179, 2019.

[74] H. Choi, J. M. Ryu, and J. H. Kim, "Tolerance Analysis of Focus-adjustable Head-mounted Displays," *Curr. Op. Photon*, vol. 1, pp. 474-490, 2017.

[75] E. Peli, G. Luo, A. Bowers, and N. Rensing, "Applications of augmented-vision head-mounted systems in vision rehabilitation," *J. Soc. Inf. Disp.*, vol. 15, pp. 1037-1045, 2007.

[76] P. Sharma, P. A. Sample, L. M. Zangwill, and J. S. Schuman, "Diagnostic Tools for Glaucoma Detection and Management," *Surv. Ophthalmol.* , vol. 53, pp. S17-S32, 2008.

[77] K. M. Kim, S.-H. Choe, J.-M. Ryu, and H. Choi, "Computation of Analytical Zoom Locus Using Padé Approximation," *Mathematics*, vol. 8, p. 581, 2020.

[78] P. Beard, "Biomedical photoacoustic imaging," *Interface Focus*, vol. 1, pp. 602-631, 2011.

[79] S. H. Seo, J. M. Ryu, and H. Choi, "Focus-Adjustable Head Mounted Display with Off-Axis System," *Applied Sciences*, vol. 10, p. 7931, 2020.

[80] H. Choi, S. Cho, and J. Ryu, "Novel Telecentric Collimator Design for Mobile Optical Inspection Instruments," *Curr. Opt. photon.*, vol. 7, pp. 263-272, 2023.

[81] S. Chee, J. Ryu, and H. Choi, "New Optical Design Method of Floating Type Collimator for Microscopic Camera Inspection," *Applied Sciences*, vol. 11, p. 6203, 2021.

[82] C. Huang, P. Lee, P. Chen, and T. Liu, "Design and implementation of a smartphone-based portable ultrasound pulsed-wave doppler device for blood flow measurement," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, vol. 59, pp. 182-188, 2012.

[83] H. Choi, S.-w. Choe, and J. Ryu, "Optical Design of a Novel Collimator System with a Variable Virtual-Object Distance for an Inspection Instrument of Mobile Phone Camera Optics," *Applied Sciences*, vol. 11, p. 3350, 2021.

[84] D. C. O'shea and D. C. C'Shea, *Elements of Modern Optical Design*. Hoboken, NJ, USA: Wiley Publishing, 1985.

[85] H. Choi, J. Ryu, and J. Kim, "A Novel Fisheye-Lens-Based Photoacoustic System," *Sensors*, vol. 16, p. 2185, 2016.

[86] W. T. Welford, *Aberrations of Optical Systems*. Boca Ration, FL, USA: CRC Press, 1986.

[87] A. Thelen, *Design of Optical Interference Coatings*. New York, NJ, USA: McGraw-Hill Companies, 1989.

[88] H. Choi, S.-w. Choe, and J.-M. Ryu, "A Macro Lens-Based Optical System Design for Phototherapeutic Instrumentation," *Sensors*, vol. 19, p. 5427, 2019.

[89] A. Yariv, *Optical Electronics*. Philadelphia, PA, USA: Saunders College Publication, 1991.

[90] H. Choi, J.-M. Ryu, and J.-Y. Yeom, "Development of a Double-Gauss Lens Based

Setup for Optoacoustic Applications," *Sensors*, vol. 17, p. 496, 2017.

[91] R. Liang, *Optical Design for Biomedical Imaging*. Washington, NJ, USA: SPIE press, 2010.

[92] P. Mouroulis and J. Macdonald, *Geometrical Optics and Optical Design*. New York, NY, USA: Oxford University Press, USA, 1997.

[93] J. L. Fergason, "Optical system for a head mounted display using a retro-reflector and method of displaying an image," 1997.

[94] H. Choi, J.-Y. Jo, and J.-M. Ryu, "A Novel Focal Length Measurement Method for Center-Obstructed Omni-Directional Reflective Optical Systems," *Appl. Sci.*, vol. 9, p. 2350, 2019.

[95] A. Petschke and P. J. La Rivière, "Comparison of intensity-modulated continuous-wave lasers with a chirped modulation frequency to pulsed lasers for photoacoustic imaging applications," *Biomed. Opt. Express*, vol. 1, pp. 1188-1195, 2010/11/01 2010.

[96] V. N. Mahajan, *Optical Imaging and Aberrations: Part I: Ray Geometrical Optics*. Bellingham, WA USA: SPIE Press, 1998.

[97] H. Choi, J.-Y. Yeom, and J.-M. Ryu, "Development of a Multiwavelength Visible-Range-Supported Opto–Ultrasound Instrument Using a Light-Emitting Diode and Ultrasound Transducer," *Sensors*, vol. 18, p. 3324, 2018.

[98] V. N. Mahajan, *Optical Imaging and Aberrations: Ray Geometrical Optics*. Washington, WA, USA: SPIE press, 1998.

[99] H. Choi, J. Jo, J.-M. Ryu, and J.-Y. Yeom, "Ultrawide-angle optical system design for light-emitting-diode-based ophthalmology and dermatology applications," *Technol. Health Care*, vol. 27, pp. 133-142, 2019.

[100] K. Worhoff, P. V. Lambeck, and A. Driessen, "Design, tolerance analysis, and fabrication of silicon oxynitride based planar optical waveguides for communication devices," *J. Lightwave Technol.*, vol. 17, pp. 1401-1407, 1999.

[101] B. H. Walker, *Optical Design for Visual Systems*. Bellingham, WA, USA: SPIE Press, 2000.

[102] H. Choi, J. J. Jeong, and J. Kim, "Development of an Estimation Instrument of Acoustic Lens Properties for Medical Ultrasound Transducers," *J. Healthcare Eng.*, vol. 2017, p. 6580217, 2017.

[103] M. J. Kidger, *Intermediate Optical Design*. Bellingham, WA, USA: SPIE Publications, 2004.

[104] H. Gross, F. Blechinger, and B. Achtner, *Handbook of Optical Systems*. Hoboken, NJ, USA: Wily-VCH Verlag GmbH & Co, 2005.

[105] K. Kim and H. Choi, "Novel Bandwidth Expander Supported Power Amplifier for Wideband Ultrasound Transducer Devices," *Sensors*, vol. 21, p. 2356, 2021.

[106] C. Ying, Z. Zhaoying, and Z. Ganghua, "Effects of different tissue loads on high power ultrasonic surgery scalpel," *Ultrasound Med. Biol.*, vol. 32, pp. 415-420, 2006.

[107] R. E. Brennan, *Ultrasonic Nondestructive Evaluation of Armor Ceramics*. Ann Arbor, MA, USA: ProQuest, 2007.

[108] H. Choi, P. C. Woo, J.-Y. Yeom, and C. Yoon, "Power MOSFET Linearizer of a High-Voltage Power Amplifier for High-Frequency Pulse-Echo Instrumentation," *Sensors*, vol. 17, p. 764, 2017.

[109] W. D. O'Brien, "Ultrasound—biophysics mechanisms," *Prog Biophys Mol Biol*, vol. 93, pp. 212-255, 08/08 2007.

[110] H. Choi and K. K. Shung, "Novel power MOSFET-based expander for high frequency ultrasound systems," *Ultrasonics*, vol. 54, pp. 121-130, 2014.

[111] H. Chang-Hong, K. A. Snook, C. Poi-Jie, and K. K. Shung, "High-frequency ultrasound annular array imaging. Part II: digital beamformer design and imaging," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, vol. 53, pp. 309-316, 2006.

[112] H. Chang-Hong, X. Xiao-Chen, J. M. Cannata, J. T. Yen, and K. K. Shung, "Development of a real-time, high-frequency ultrasound digital beamformer for high-frequency linear array transducers," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, vol. 53, pp. 317-323, 2006.

[113] H. Choi and K. K. Shung, "Protection circuits for very high frequency ultrasound systems," *J. Med. Syst.*, vol. 38, p. 34, 2014.

[114] H. Choi, "A Doherty Power Amplifier for Ultrasound Instrumentation," *Sensors*, vol. 23, p. 2406, 2023.

[115] H. Choi and S.-w. Choe, "Therapeutic Effect Enhancement by Dual-bias High-voltage Circuit of Transmit Amplifier for Immersion Ultrasound Transducer Applications," *Sensors*, vol. 18, p. 4210, 2018.

[116] W.-W. Liu, S.-W. Liu, Y.-R. Liou, Y.-H. Wu, Y.-C. Yang, C.-R. C. Wang, and P.-C. Li, "Nanodroplet-Vaporization-Assisted Sonoporation for Highly Effective Delivery of Photothermal Treatment," *Sci. Rep.*, vol. 6, p. 24753, 2016.

[117] H. Choi, J.-M. Ryu, and S.-w. Choe, "A novel therapeutic instrument using an ultrasound-light-emitting diode with an adjustable telephoto lens for suppression of tumor cell proliferation," *Measurement*, vol. 147, p. 106865, 2019.

[118] J. L. Prince and J. M. Links, *Medical Imaging Signals and Systems*. Upper Saddle River, NJ, USA: Pearson Prentice Hall 2006.

[119] H. Choi, C. Park, J. Kim, and H. Jung, "Bias-Voltage Stabilizer for HVHF Amplifiers in VHF Pulse-Echo Measurement Systems," *Sensors*, vol. 17, p. 2425, 2017.

[120] H. Li, Y. C. Li, D. Zhou, J. Peng, H. S. Luo, and J. Y. Dai, "Application of PMNPT single crystal in a 3.2 MHz phased-array ultrasonic medical imaging transducer," in *IEEE Ultrason. Symp.*, 2007, pp. 572-574.

[121] J. Udesen, F. Gran, K. L. Hansen, J. A. Jensen, C. Thomsen, and M. B. Nielsen, "High frame-rate blood vector velocity imaging using plane waves: Simulations and preliminary experiments," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, vol. 55, pp. 1729-1743, 2008.

[122] H. Choi and S.-w. Choe, "Acoustic Stimulation by Shunt-Diode Pre-Linearizer Using Very High Frequency Piezoelectric Transducer for Cancer Therapeutics," *Sensors*, vol. 19, p. 357, 2019.

[123] A. Maxwell, S.-W. Huang, L. Tao, K. Jin-Sung, S. Ashkenazi, and L. Jay Guo, "Polymer Microring Resonators for High-Frequency Ultrasound Detection and Imaging," *IEEE J. Sel. Top. Quantum Electron.*, vol. 14, pp. 191-197, 2008.

[124] H. Ammari, *An Introduction to Mathematics of Emerging Biomedical Imaging*. Berlin, Germany: Springer, 2008.

[125] S.-w. Choe and H. Choi, "Suppression Technique of HeLa Cell Proliferation Using Ultrasonic Power Amplifiers Integrated with a Series-Diode Linearizer," *Sensors*, vol. 18, p. 4248, 2018.

[126] H. Choi, M. Qian, M. G. Kim, H. Zheng, H. K. Choi, B. Zhang, and K. K. Shung, "Analog Wideband Receiver Architecture for High Frequency Ultrasound Instrumentation," *J. Med. Imaging Health Inf.*, vol. 6, pp. 47-52, 2016.

[127] S. Y. Emelianov, P.-C. Li, and M. O'Donnell, "Photoacoustics for molecular imaging and therapy," *Phys. Today*, vol. 62, pp. 34-39, 2009.

[128] H. Choi, M. Kim, T. Cumins, J. Hwang, and K. Shung, "Power MOSFET-diode-based limiter for high frequency ultrasound systems," *Ultrason. Imaging*, vol. 37, pp. NP1-NP1, 2015.

[129] C.-H. Chen, *Ultrasonic and advanced methods for nondestructive testing and material characterization*. London, United Kingdom: World Scientific, 2007.

[130] M. Mitsuishi, S. i. Warisawa, T. Tsuda, T. Higuchi, N. Koizumi, H. Hashizume, and K. Fujiwara, "Remote ultrasound diagnostic system," in *Proceedings 2001 ICRA. IEEE International Conference on Robotics and Automation (Cat. No. 01CH37164)*, Seoul, Korea, 2001, pp. 1567-1574.

[131] H. Choi, H.-C. Yang, and K. K. Shung, "Bipolar-power-transistor-based limiter for high frequency ultrasound imaging systems," *Ultrasonics*, vol. 54, pp. 754-758, 2014.

[132] W. Jun-ru and N. Wesley, *Emerging Therapeutic Ultrasound*. Hackensack, NJ, USA: World Scientific Publishing, 2006.

[133] U. Jung, J. Ryu, and H. Choi, "Optical Light Sources and Wavelengths within the Visible and Near-Infrared Range Using Photoacoustic Effects for Biomedical Applications," *Biosensors*, vol. 12, p. 1154, 2022.

[134] T. Yu, Z. Wang, and T. J. Mason, "A review of research into the uses of low level ultrasound in cancer therapy," *Ultrason. Sonochem.*, vol. 11, pp. 95-103, 2004.

[135] H. Jung, R. Wodnicki, H. G. Lim, C. W. Yoon, B. J. Kang, C. Yoon, C. Lee, J. Y. Hwang, H. H. Kim, and H. Choi, "CMOS High-Voltage Analog 1–64 Multiplexer/Demultiplexer for Integrated Ultrasound Guided Breast Needle Biopsy," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, vol. 65, pp. 1334-1345, 2018.

[136] T. A. Tran, S. Roger, J. Y. Le Guennec, F. Tranquart, and A. Bouakaz, "Effect of ultrasound-activated microbubbles on the cell electrophysiological properties," *Ultrasound Med. Biol.*, vol. 33, pp. 158-163, 2007.

[137] H. Choi, "Development of negative-group-delay circuit for high-frequency ultrasonic transducer applications," *Sens. Actuators, A*, vol. 299, p. 111616, 2019.

[138] K. Iniewski, *Medical Imaging*. Hoboken, NJ, USA: Wiley Online Library, 2009.

[139] W. Davros, *Medical Imaging Principles, Detectors, and Electronics*. Hoboken, NJ, USA: John Wiley & Sons, 2009.

[140] H. Choi, J. Ryu, and J.-Y. Yeom, "A Cost-effective Light Emitting Diode-acoustic System for Preclinical Ocular Applications," *Curr. Op. Photon*, vol. 2, pp. 59-68, 2018.

[141] K. Iniewski, *Medical imaging: principles, detectors, and electronics*. Hoboken, NJ, USA: John Wiley & Sons, 2009.

[142] J. L. Su, B. Wang, K. E. Wilson, C. L. Bayer, Y.-S. Chen, S. Kim, K. A. Homan, and S. Y. Emelianov, "Advances in Clinical and Biomedical Applications of Photoacoustic Imaging," *Expert opinion on medical diagnostics*, vol. 4, pp. 497-510, 2010.

[143] H. Choi, "Development of a Class-C Power Amplifier with Diode Expander Architecture for Point-of-Care Ultrasound Systems," *Micromachines*, vol. 10, p. 697, 2019.

[144] J. Davidse, *Analog Electronic Circuit Design*. Upper Saddle River, NJ, USA: Prentice Hall, 1991.

[145] P. E. Allen and D. R. Holberg, *CMOS Analog Circuit Design*. Oxford, United Kingdom: Oxford University Press, 2002.

[146] H. Choi, "Pre-Matching Circuit for High-Frequency Ultrasound Transducers," *Sensors*, vol. 22, p. 8861, 2022.

[147] J. Yun, H. Choi, and J. Kim, "Low-noise wide-bandwidth DNA readout instrument for nanopore applications," *Electron. Lett.*, vol. 53, pp. 706-708, 2017.

[148] K. You and H. Choi, "Inter-Stage Output Voltage Amplitude Improvement Circuit Integrated with Class-B Transmit Voltage Amplifier for Mobile Ultrasound Machines," *Sensors*, vol. 20, p. 6244, 2020.

[149] N. B. Smith and A. Webb, *Introduction to Medical Imaging: Physics, Engineering and Clinical Applications*. Cambridge, United Kingdom: Cambridge university press, 2010.

[150] W.-K. Chen, "High Performance Analog Circuits," in *The Circuits and Filters Handbook*, ed Boca Raton, FL, USA: CRC Press, 2002.

[151] A. B. Grebene, *Bipolar and MOS analog integrated circuit design*. Hoboken, NJ, USA: John Wiley & Sons, 2002.

[152] K. You, S.-H. Kim, and H. Choi, "A Class-J Power Amplifier Implementation for Ultrasound

Device Applications," *Sensors*, vol. 20, p. 2273, 2020.

[153] R. Weissleder, *Molecular Imaging: Principles and Practice*. Shelton, CT, USA: People's Medical Publising House, 2010.

[154] G. M. Matte, P. L. M. J. Van Neer, M. G. Danilouchkine, J. Huijssen, M. D. Verweij, and N. de Jong, "Optimization of a phased-array transducer for multiple harmonic imaging in medical applications: frequency and topology," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control* vol. 58, pp. 533-546, 2011.

[155] J. Kim, K. Kim, S.-H. Choe, and H. Choi, "Development of an Accurate Resonant Frequency Controlled Wire Ultrasound Surgical Instrument," *Sensors*, vol. 20, p. 3059, 2020.

[156] F. A. Jolesz and K. H. Hynynen, *MRI-guided Focused Ultrasound Surgery*. Boca Raton, FL, USA: CRC Press, 2007.

[157] K. You and H. Choi, "Wide Bandwidth Class-S Power Amplifiers for Ultrasonic Devices," *Sensors*, vol. 20, p. 290, 2020.

[158] I. O. Wygant, Z. Xuefeng, D. T. Yeh, O. Oralkan, A. S. Ergun, M. Karaman, and B. T. Khuri-Yakub, "Integration of 2D CMUT arrays with front-end electronics for volumetric ultrasound imaging," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, vol. 55, pp. 327-342, 2008.

[159] J. S. Suri, C. Kathuria, R.-F. Chang, F. Molinar, and A. Fenster, *Advances in Diagnostic and Therapeutic Ultrasound Imaging*. Norwood, MA, USA: Artech House, 2008.

[160] H. Choi, "Power Amplifier Design for Ultrasound Applications," *Micromachines*, vol. 14, p. 1342, 2023.

[161] H. Choi, H. Jung, and K. K. Shung, "Power Amplifier Linearizer for High Frequency Medical Ultrasound Applications," *J. Med. Biol. Eng.*, vol. 35, pp. 226-235, 2015.

[162] M. A. Flower, *The Physics of Medical Imaging*. Boca Raton, FL, USA: CRC Press, 2012.

[163] H. Choi and K. K. Shung, "Crossed SMPS MOSFET-based protection circuit for high frequency ultrasound transceivers and transducers," *Biomed. Eng. Online*, vol. 13, p. 76, 2014.

[164] C. Toumazou, G. S. Moschytz, and B. Gilbert, *Trade-offs in Analog Circuit Design: the Designer's Companion*. Berlin, Germany: Springer Science & Business Media, 2004.

[165] B. Rao, K. Maslov, A. Danielli, R. Chen, K. K. Shung, Q. Zhou, and L. V. Wang, "Real-time four-dimensional optical-resolution photoacoustic microscopy with Au nanoparticle-assisted subdiffraction-limit resolution," *Opt. Lett.*, vol. 36, pp. 1137-1139, 2011/04/01 2011.

[166] H. Choi, C. Yoon, and J.-Y. Yeom, "A Wideband High-Voltage Power Amplifier Post-Linearizer for Medical Ultrasound Transducers," *Appl. Sci.*, vol. 7, p. 354, 2017.

[167] J. T. Bushberg and J. M. Boone, *The Essential Physics of Medical Imaging*. Philadelphia, PA, USA: Lippincott Williams & Wilkins, 2011.

[168] H. Choi and S.-H. Shin, "Novel random number generation for ultrasound systems," *J. Nonlinear Convex Anal.*, vol. 24, pp. 1835-1841, 2023.

[169] A. Needles, A. Heinmiller, J. Sun, C. Theodoropoulos, D. Bates, D. Hirson, M. Yin, and F. S. Foster, "Development and initial application of a fully integrated photoacoustic micro-ultrasound system," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control* vol. 60, pp. 888-897, 2013.

[170] H. Choi, C. Yoon, and S.-H. Shin, "Development of a Novel Image Compression Algorithm for Point-of-Care Ultrasound Applications," *J. Med. Imaging Health Inf.*, vol. 8, pp. 1526-1531, 2018.

[171] H. Choi, "Prelinearized Class-B Power Amplifier for Piezoelectric Transducers and Portable Ultrasound Systems," *Sensors*, vol. 19, p. 287, 2019.

[172] S. Ibsen, C. E. Schutt, and S. Esener, "Microbubble-mediated ultrasound therapy: a review of its potential in cancer treatment," *Drug Des. Dev. Ther.*, vol. 7, pp. 375-388, 2013.

[173] U. Jung and H. Choi, "Active echo signals and image optimization techniques via software filter correction of ultrasound system," *Applied Acoustics*, vol. 188, p. 108519, 2022.

[174] K. W. Jang, *The Effect of Low-intensity Pulsed Ultrasound on Chondrocyte Migration and its Potential for the Repair of Articular Cartilage*: The University of Iowa, 2011.

[175] A. R. Carson, C. F. McTiernan, L. Lavery, A. Hodnick, M. Grata, X. Leng, J. Wang, X. Chen, R. A. Modzelewski, and F. S. Villanueva, "Gene Therapy of Carcinoma Using Ultrasound-Targeted Microbubble Destruction," *Ultrasound Med. Biol.*, vol. 37, pp. 393-402, 2011.

[176] J. J. Jeong and H. Choi, "An impedance measurement system for piezoelectric array element transducers," *Measurement*, vol. 97, pp. 138-144, 2017.

[177] Y.-F. Zhou, "High intensity focused ultrasound in clinical tumor ablation," *World J. Clin. Oncol.*, vol. 2, pp. 8-27, 2011.

[178] H. Choi, "Harmonic-Reduced Bias Circuit for Ultrasound Transducers," *Sensors*, vol. 23, p. 4438, 2023.

[179] S.-P. Heo and H. Choi, "Development of a robust eye exam diagnosis platform with a deep learning model," *Technol. Health Care*, vol. 31, pp. 423-428, 2023.

[180] H. Choi and S.-H. Shin, "Secured computed tomography scanner using a random bit," *Technol. Health Care*, vol. 31, pp. 55-59, 2023.

[181] L. Zeng, G. Liu, D. Yang, and X. Ji, "Cost-efficient laser-diode-induced optical-resolution photoacoustic microscopy for two-dimensional/three-dimensional biomedical imaging," *J. Biomed. Opt.*, vol. 19, p. 076017, 2014.

[182] H. Choi, J. Park, W. Lim, and Y.-M. Yang, "Active-beacon-based driver sound separation system for autonomous vehicle applications," *Appl. Acoust.*, vol. 171, p. 107549, 2021.

[183] A. Banuaji and H.-K. Cha, "A 15-V bidirectional ultrasound interface analog front-end IC for medical imaging using standard CMOS technology," *IEEE Trans. Circuits Syst. II Express Briefs*, vol. 61, pp. 604-608, 2014.

[184] J. Kim, J. Ko, H. Choi, and H. Kim, "Printed Circuit Board Defect Detection Using Deep Learning via A Skip-Connected Convolutional Autoencoder," *Sensors*, vol. 21, p. 4968, 2021.

[185] M. M. El-Desouki and K. Hynynen, "Driving Circuitry for Focused Ultrasound Noninvasive Surgery and Drug Delivery Applications," *Sensors* vol. 11, pp. 539-556, 2011.

[186] J. Lee, J. Ryu, and H. Choi, "A Novel Analytical Interpolation Approach for Determining the Locus of a Zoom Lens Optical System," *Photonics*, vol. 11, p. 303, 2024.

[187] F. Yan, X. Li, Q. Jin, C. Jiang, Z. Zhang, T. Ling, B. Qiu, and H. Zheng, "Therapeutic Ultrasonic Microbubbles Carrying Paclitaxel and LyP-1 Peptide: Preparation, Characterization and Application to Ultrasound-Assisted Chemotherapy in Breast Cancer Cells," *Ultrasound Med. Biol.*, vol. 37, pp. 768-779, 2011.