Progress in Ultrasonic Imaging: from the beginning to the cutting edge

Roman Maev[1]

[1]Physics, Institute of Diagnostic Imaging Research, Canada

While a picture is worth a thousand words, in science a single image is often problematic. Imaging technology is largely based on manipulating optical waves, but since optical waves limit us to surface images, in the twentieth century we turned to other technologies, such as X-rays, ultrasound, infrared, CT, magneto-resonance, microwaves, etc. Our review is focused on ultrasonic imaging which is now an integral and important part of our continuing effort to extend our ability to "see" in both medicine and industry. In 1793 Italian biologist Lazzaro Spallanzani during his extensive experiments discovered that bats could fly at night and detect objects (including prey) and avoid obstacles and concluded that bats do not use their eyes for navigation, but some other sense. He proposed that it was some new waves undetectable to human ears, but the exact scientific fact that these waves were ultrasound was discovered only in 1938, by two American biologists Donald Griffin and Robert Galambos. Perhaps the first practical use of the piezoelectric effect and ultrasonic transducer was by the French physicist Paul Langevin who in 1917 built a passive ultrasonic device to detect German submarines during the First World War. Later he was the first to initiate the study of ultrasound radiation on biological bodies. During the 1920s and 1930s extensive studies began on the biological effects of ultrasound, especially at high power levels, as a new powerful instrument for the therapy of various diseases. The idea of ultrasonic visualisation surfaced in the Soviet Union by Sergei Y. Sokolov when he used electro-acoustic apparatus to generate high frequency sound in water to visualize and image various objects. In his research Sokolov demonstrated the first ultrasound image at high frequency and proved that such images might compete with optical instruments. As a result, he was granted patents by USSR and USA (first on N 11371 in USSR in 1929 and second N 2 164125 in USA in 1937). In 1942 Firestone (known best for its tires) filed a patent for a pulse-echo ultrasound device to detect flaws in materials such as rubber. However, the patent also suggested that the same device could be used to "detect flaws in the human body." During the 1950s pioneering research groups in Europe, USA, and Japan all developed the first generation of ultrasonic imaging devices for diagnostic medicine and proved the significant value they could offer. Due to the limited ability of piezoelectrical materials at that time, high frequency range application did not begin research until the beginning of the 60s. Serios progress in the development of piezoelectric materials was achieved at the end of the 60s and allowed for further progress to be achieved. At the Zenith laboratory in Chicago, USA, Larry Kessler and Adrian Korpel developed an acoustic system in which a scanned laser beam reads the image from a plastic membrane deformed by the acoustic signal. At Stanford University, Calvin Quate and Bertram Auld with their students demonstrated and analysed several systems of microscopic acoustic imaging at the frequency of 50 MHz and later 100 MHz. These pioneer researchers, alongside others from UK, Europe, Germany, USSR, and Japan established many of the basic principles of acoustic microscopy, and their work influenced all that followed. As a result, the first commercial microscope with a broad frequency range from 50 MHz up to 1 GHz was introduced by Leica Corp (Germany) in 1985 to the global market and found commercial success. Although ultrasonic images do not provide the same details found in magnetic resonance images (MRI) or X-ray, the ultrasonic imaging system provides significant information at one-tenth the cost of MRI, with the added advantage of being completely safe for the patient's health. This form of imaging is particularly useful for obtaining data from inside the human body, for delineating the interfaces between hard biological tissue (i.e. bone) and spaces in muscles and soft tissues. The role of high-resolution ultrasonic imaging in academic studies of condensed matter and various applications of microstructural material characterization in physics, biology, and technology is rapidly increasing. The whole spectrum of original physical and methodological approaches to ultrasonic imaging results in a significant improvement in the quality of developed technology together with implementation of various highly efficient quantitative methods. The new generations of high-resolution ultrasonic imaging systems continue to decrease in size and will soon enter the realm of pocket-sized dimensions. New transducer materials, including advanced composites and recent MEMS applications to novel array solutions, also contribute to substantial changes in the design of ultrasonic imaging systems. Novel physical solutions, including new results in the field of adaptive methods and inventive approaches to inverse problems, original concepts based on high harmonic imaging algorithms, advanced super resolution imaging algorithms, intriguing vibro-acoustic imaging, and vibro-modulation technique, the most of them have been successfully introduced and verified in numerous studies of industrial materials and biomaterials in the last few years. Together with the above-mentioned traditional academic and practical avenues in high resolution ultrasonic imaging research, intriguing scientific discussions have recently surfaced in various fields and will hopefully continue to bear fruit in the future. The goal of this review is to provide an overview of the progress in high-resolution ultrasonic imaging: from the beginning to the future and provide recent advances in high-resolution ultrasonic imaging techniques and their applications to biomaterials evaluation and industrial materials.