A review on Ultrasound imaging in Medical and Industrial Application.

Introduction: The leading development of Ultrasound imaging in biomedical and industrial area started from 1950 due to its noninvasive and non-ionized characteristics. In the last decades, ultrasound imaging has contributed in the advancement of numerical technologies such as signal processing. There are namely three reasons behind this advancement. The first one is linked to important advances in transducers (used for generation and detection of ultrasound) technology. The second is the improvement brought by advances in digital technologies, and namely advances in signal and image processing methods and technologies. The last one is the wide variety of applications in medical as well as in industrial areas. However, the use of ultrasound imaging has increased the need for signal processing techniques. I this work I reviewed the up-to-date developments in ultrasound imaging techniques, including elementary principles, signal acquisition and processing, from one dimensional to multidimensional systems.

ULTRASOUND SIGNAL ACQUISITION SYSTEMS:

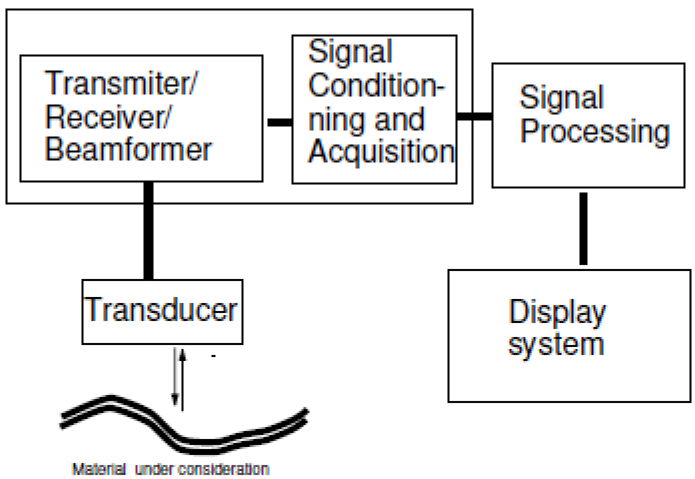


Fig 1: Ultrasound Image acquisition system

All ultrasound systems consist of five parts as shown in Fig.1. The first includes an acoustical part, the transducer, which performs both the generation and the detection of ultrasound. This transducer may consist of one element (which has to move) or of multiple elements for multidimensional signal acquisition. The typical working frequency depends on the materials investigated by ultrasound. These frequencies are basically less than 500 KHz in air and range from 1 MHz in some liquids or biological tissue up to 50 or 100 MHz in some special applications. The second one is the electronic part which controls the US signal emission, beamforming, reception, and conditioning. The third and fourth parts are respectively US signal acquisition processing and display. And finally the fifth part is the material or tissue under consideration. The basic principle of US imaging consists in emitting US waves thanks to a transducer toward the material under consideration and receiving the reflected (echo) waves which result from the interaction between US waves and the material. The relevant signals are detected by the electronic part, conditioned, acquired, processed and displayed in an appropriate format.US image is in fact a collection of individual signals reflected from each interface inside the material. The exact processing depends on the US characteristics of the materials and the type of information required. However, the resulting signal or image quality that is its ability to restore information existing in the material, depends for a large part on the characteristics of the transducers such as central frequency and bandwidth.

ONE DIMENSIONAL SIGNAL PROCESSING: TIME, FREQUENCY AND VELOCITY ESTIMATION

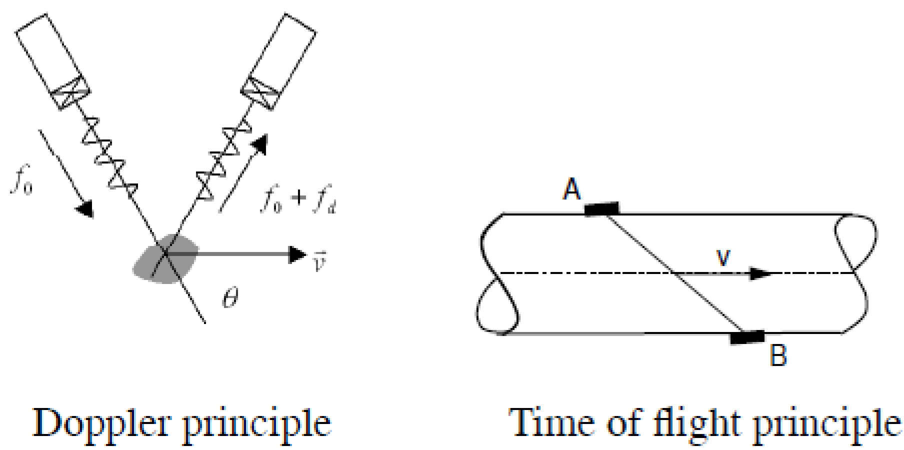


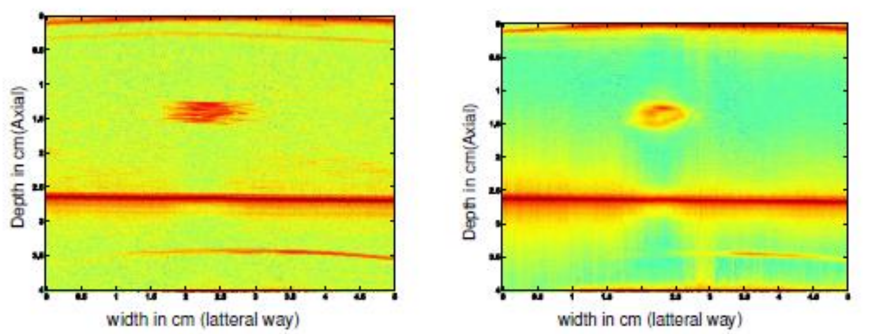
Fig 2: Velocity estimation principle

The primary aim of 1D US signal processing is to extract some parameters form the US signal for estimation or detection purpose. One important matter of concern is flow velocity estimation. Two kinds of techniques are used for this purpose.

The first one is Doppler signal processing. Blood flow in vessels and pipe fluid flow in industrial applications can be accessed through analysis of the signal. Doppler signals are obtained by directing an ultrasound beam to a moving flow containing backscattering particles Fig.2. The wave reflected from the particle is slightly Doppler-shifted by the movement of the particles. After in-phase demodulation, the Doppler signal containing the Doppler frequency shift is used to extract flow velocity (which is proportional to Doppler frequency shift). Although the Doppler principle seems simple, in practice, the precise determination of the Doppler frequency is sometimes cumbersome because of physical phenomena that introduce inaccuracies in estimation of the velocity.

The second one is the so-called time of flight technique. In this case the velocity estimation does not require the presence of particles in the flow. Transducers located on each side of the flow are used to acquire the signal from two areas (A and B for instance), Fig.2. The flow velocity is evaluated by estimating time of flight of the US in the fluid. Here, the velocity estimation is based either on narrow band or wide band correlation techniques,[1],[2].These kinds of velocity estimations are used in industrial area namely for US flowmeters.

2D IMAGING:



Original resolution improved using AR

Fig 3 : B-mode image of resolution improvement.

US Image processing has been mainly centered on 2D image manipulation. Basically, 2D US imaging systems operate in Brightness-mode or B-mode Fig.3. A typical B-mode image is obtained from of a set individual radio-frequency (RF) signals by filtering, envelope detection and then log-compression,[3].

This kind of processing as well as the characteristics of the transducer and the materials may result in low resolution either axially (in the direction of the US beam) or laterally (in the perpendicular direction) through blurring effects contributing to a poor quality image. Improving 2D US image resolution is a major concern which has given rise to an important number of works. Many directions have been followed; the two main being novel transducer designs and signal processing improvement. Here, we deal with this last direction. If a part of works use B-mode images, a great number of works deal with RF signals since they contain the overall information available on the imaged material and their improvement leads to improvement of B-mode images. The problem of 2D US image resolution improvement can be expressed in terms of convolution. The radio-frequency signal $y(a,b)$ can be expressed as :

$$y(a,b) = h(a,b) * x(a,b) + \eta(a.b) \quad \text{---------------------}(1)$$

where a is the axial direction index and b is the lateral one. $x(a,b)$ is the reflectivity function of an individual point of the imaged material, $h(a,b)$ is the system impulse response and $\eta(a,b)$ is an additive noise term. This convolution may be separated into two independent convolutions; one in the axial direction and another in the lateral direction.

3D AND 4D IMAGING:

Although 2D US imaging offers very acute understanding of the imaged media, it has some intrinsic limitations; the main of which being 2D viewing of 3D structures. This requires a mind reconstruction of actual 3D structures, which is in some situations difficult to achieve. A way to overcome this is to take multiple scans of some particular locations and to quantitatively analyze them afterwards. This is particularly time consuming. 3D and 4D may thus be used to overcome these limitations. 4D US imaging is real-time 3D US imaging in which time is taken as the fourth coordinate.

The starting point of 3D/4D US imaging is, like in the 2D case, the acquisition system. The basic principle consists in the acquisition of a volume data set. Most of current methods consist in acquiring a series of 2D images in a volume of interest while moving the transducer (which is of course a specific transducer) using a motor. This implies additional techniques for processing a slice within the volume and taking into account the motion when imaged objects move. Many relevant imaging techniques have been developed recently. [4],[5], [6].

Conclusion:

I reviewed the main ultrasound imaging systems and techniques from 1D signals to 4D images. The part played by signal and image processing has become larger and larger, and current trends in new applications, both in industrial and biomedical fields, are a sign that this part will keep on growing. Finally, several practical developments have been presented and also discussed during the oral presentation in this special session.

Reference:

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