Milan Šonka
Ioannis A. Kakadiaris
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Computer Vision and Mathematical Methods in Medical and Biomedica Image Analysis

ECCV 2004 Workshops CVAMIA and MMBIA
Prague, Czech Republic, May 2004
Revised Selected Papers

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Preface

Medical imaging and medical image analysis are rapidly developing. While medical imaging has already become a standard of modern medical care, medical image analysis is still mostly performed visually and qualitatively. The ever-increasing volume of acquired data makes it impossible to utilize them in full. Equally important, the visual approaches to medical image analysis are known to suffer from a lack of reproducibility. A significant research effort is devoted to developing algorithms for processing the wealth of data available and extracting the relevant information in a computerized and quantitative fashion.

Medical imaging and image analysis are interdisciplinary areas combining electrical, computer, and biomedical engineering; computer science; mathematics; physics; statistics; biology; medicine; and other fields. Medical imaging and computer vision, interestingly enough, have developed and continue developing somewhat independently. Nevertheless, bringing them together promises to benefit both of these fields. We were enthusiastic when the organizers of the 2004 European Conference on Computer Vision (ECCV) allowed us to organize a satellite workshop devoted to medical image analysis.

In a short time after the announcement, we received 60 full-length paper submissions, out of which 13 were accepted for oral and 25 for poster presentation after a rigorous peer-review process. The workshop included a keynote lecture and two invited talks. The keynote, entitled *Progress in Quantitative Cardiovascular Imaging*, was presented by Prof. Johan H.C. Reiber from the Leiden University Medical Center, The Netherlands. The first invited talk was given by Prof. Michael Unser from the Swiss Federal Institute of Technology, Lausanne (EPFL), Lausanne, Switzerland – titled *Wavelets, Fractals and Medical Image Analysis*. The second invited talk dealt with *Inverse Consistent Medical Image Registration* and was presented by Prof. Gary E. Christensen from the University of Iowa, Iowa City IA, USA.

The workshop logistics were handled by the organizers of the ECCV 2004, associated with the Centre for Machine Perception of the Czech Technical University in Prague, Czech Republic. We are grateful to all Centre members and students for the smooth organizational support during the entire workshop, as well as for providing a friendly working atmosphere. Finally, we extend our sincere thanks to the program committee members, to the reviewers, and to everyone else who made this workshop possible.

May 2004

Milan Šonka
Ioannis A. Kakadiaris
Jan Kybic

Organization

The 2004 *Computer Vision Approaches to Medical Image Analysis* (CVAMIA) and *Mathematical Methods in Biomedical Image Analysis* (MMBIA) Workshop was held in conjunction with the 8th *European Conference on Computer Vision* (ECCV) in Prague, on May 15, 2004. The ECCV conference was organized by the Centre for Machine Perception, Department of Cybernetics, Faculty of Electrical Engineering, Czech Technical University, Prague, Czech Republic.

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Ultrasound Stimulated Vibro-acoustography

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Abstract. Vibro-acoustography is a method of imaging and measurement that uses ultrasound to produce radiation force to vibrate objects. The radiation force is concentrated laterally by focusing the ultrasound beam. The radiation force is limited in depth by intersecting two beams at different frequencies so that there is interference between the beams at the difference frequency only at their intersection. This results in a radiation stress of limited spatial extent on or within the object of interest. The resulting harmonic displacement of the object is detected by acoustic emission, ultrasound Doppler, or laser interferometery. The displacement is a complicated function of the object material parameters. However, significant images and measurements can be made with this arrangement. Vibro-acoustography can produce high resolution speckle free images of biologically relevant objects such as breast micro-calcification and vessel calcifications, heart valves, and normal arteries. Vibro-acoustography can also make spot measurements such as microbubble contrast agent concentration in vessels. Several examples of these results will be described.

1 Introduction

It is well known that changes in the elasticity of soft tissues are often related to pathology. Traditionally, physicians use palpation as a simple method for estimating the mechanical properties of tissue. Physicians use a static force applied with their hands and obtain a crude estimation of tissue elasticity the sense of touch. Thus, the force is applied on the body surface and the result is a collective response of all the tissues below. Clinicians can sense abnormalities if the response to palpation is sufficiently different from that of normal tissue. However, if the abnormality lies deep in the body, or if is too small to be resolved by touch, then palpation fails. The dynamic response of soft tissue to a force is also valuable in medical diagnosis. For instance, rebound of tissue upon sudden release of pressure exerted by the physician's finger on the skin provides useful diagnostic information about the tissue.

Quantitative measurement of the mechanical properties of tissues and their display in raster format is the aim of a class of techniques generally called elasticity imaging, or elastography. The general approach is to measure tissue motion caused by an external (or, in some methods, internal) force and use the degree of displacement to reconstruct the elastic parameters of the tissue. The excitation stress can be either

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static or dynamic (vibration). Dynamic excitation is of particular interest because it provides more comprehensive information about tissue properties over a spectrum of frequencies. In many elasticity imaging methods, ultrasound is used to detect the motion or displacement resulting from the applied stress. Magnetic resonance elastography is a recently developed method [1] that employs a mechanical actuator to vibrate the body surface and then measures the resulting strain waves with a phase sensitive magnetic resonance imaging (MRI) machine.

The majority of elasticity imaging methods is based on an external source of force in which the object is pressed by a known amount of force or displacement, and the resulting internal deformations are measured by means of pulse-echo ultrasound. The elasticity of the region of interest is then calculated based on the resulting deformation in relation to the magnitude of the applied force (or displacement). Normally, the region of interest rests deep in the body and away from the source of the force. The problem with this method, termed elastography, is that the force actually exerted on the region of interest depends on the elastic properties of the tissues located between the source and the region of interest. Hence, the deformation and the estimated elasticity of the region of interest are subject to the variability of the intervening tissues.

An alternative strategy is to apply a localized stress directly in the region of interest. One way to accomplish this is to use the radiation pressure of ultrasound. Acoustic radiation force is the time average force exerted by an acoustic field on an object. This force is produced by a change in the energy density of an incident acoustic field [2]; for example, due to absorption or reflection. The use of ultrasound radiation force for evaluating tissue properties has several benefits, for example:

(a) Acoustic (ultrasound) energy is a non-invasive means of exerting force.
(b) Existing ultrasound technology and devices can be readily modified for this purpose, thus eliminating the need for developing a new technology.
(c) Radiation force can be generated remotely inside tissue without disturbing superficial layers.
(d) The radiation stress field can be highly localized, thus allowing for interrogation of a small excitation point.
(e) Radiation force can be produced in a wide range of frequencies or temporal shapes.

These features make radiation force methods highly attractive compared to other, mostly mechanical excitation methods used in elasticity imaging. Tissue probing with the radiation force of ultrasound can be accomplished with a variety of methods depending on the excitation and detection methods used. Similar to elasticity imaging methods with mechanical excitation, radiation force methods can use either a static or dynamic stress.

Using a dynamic radiation force to remotely probe tissue has certain unique characteristics and capabilities that can provide a new family of methods in the field of tissue characterization and imaging. It is insightful to set this new field apart from conventional ultrasound tissue characterization imaging. A major difference is that the dynamic radiation stress allows one to analyze the object based on its low frequency structural vibration properties as opposed to its ultrasonic parameters.

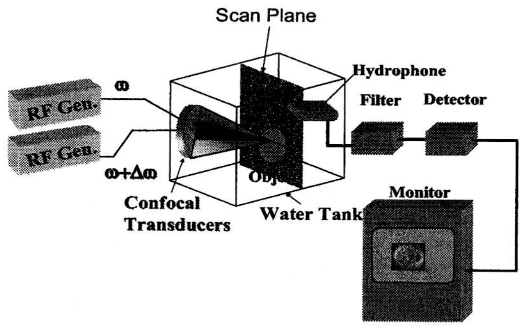

Fig. 1. Schematic of experiment setup

The dynamic radiation force methods may be categorized as:

(a) Transient methods, where an impulsive radiation force is used and the transient response of the tissue is detected by Doppler ultrasound [3].

(b) Shear-wave methods, where an impulsive or oscillating radiation is applied to the tissue and the resulting shear wave is detected by ultrasound or other methods [4,5,6].

(c) Vibro-acoustography, a method recently developed by the authors, where a localized oscillating radiation force is applied to the tissue and the acoustic response of the tissue is detected by a hydrophone or microphone [7].

Fig. 2. Vibro-acoustic image of US quarter obtained with the setup of Fig. 1.

2 Theory

Acoustic radiation force is a time average force exerted by a propagating acoustic wave on an object. This force is an example of a universal phenomenon in any wave motion that introduces some type of unidirectional force on absorbing or reflecting targets in the wave path. For a review of this topic the reader may refer to [2].

Consider a plane ultrasound beam interacting with a planar object of zero thickness and arbitrary shape and boundary impedance that scatters and absorbs. The radiation force vector, $\boldsymbol{F}$, arising from this interaction has a component in the beam direction and another transverse to it. The magnitude of this force is proportional to the average energy density of the incident wave E at the object, where $<>$ represents the time average, and S the area of the projected portion of the object [8]:

$$\boldsymbol{F} = \boldsymbol{dr} S <E> . \tag{1}$$

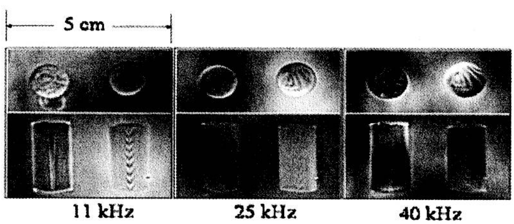

Fig. 3. Vibro-acoustic image of a hard (left) and a soft (right) urethane cylinder embedded within agar gel. Top row are images from the ends of the cylinders and bottom row are imaged from the side of the cylinders. The low difference frequencies, 11 kHz and 25 kHz. show the difference in stiffness of the two cylinders.

Here ***dr*** is called the vector drag coefficient with a component in the incident beam direction and another transverse to it. The coefficient ***dr*** is defined per unit incident energy density and unit projected area. For a planar object, the magnitude of ***dr*** is numerically equal to the force on the unit area of the object per unit energy density. Physically, the drag coefficient represents the scattering and absorbing properties of the object. The drag coefficient can also be interpreted as the ratio of the radiation force magnitude on a given object to the corresponding value if the object were replaced by a totally absorbing object of similar size. For simplicity, we assume a planar objected oriented perpendicular to the beam axis. In this case, the transverse component vanishes, thus, the drag coefficient (force) will have only a component normal to the target surface which we denote by scalar *dr(F)*. To produce a time-varying radiation force, the intensity of the incident beam can be modulated in various ways.