Ultrasound in Med. & Biol., Vol. 34, No. 7, pp. 1117–1128, 2008

0301-5629/08/$–see front matter

doi:10.1016/j.ultrasmedbio.2007.12.012

● *Original Contribution*

AN INTELLIGENT INTERFACE FOR FREEHAND STRAIN IMAGING

JOEL E. LINDOP, GRAHAM M. TREECE, ANDREW H. GEE, and RICHARD W. PRAGER
Department of Engineering, University of Cambridge, UK

Abstract—We present a new, intelligent interface for freehand strain imaging, which has been designed to support clinical trials investigating the potential of ultrasonic strain imaging for diagnostic purposes across a broad range of target pathologies. The aim with this interface is to make scanning easier and to help clinicians learn the necessary scanning technique quickly, by providing real time feedback indicating the quality of the strain data as they are produced. The methods require a pixel-level indicator of estimation precision, which can be calculated in-line with strain estimation. This is exploited in novel approaches to normalisation, persistence and display. The effect of each component is indicated in the results with examples from *in vitro* and *in vivo* scanning. As well as providing real-time feedback, the images are easier to interpret because data at unacceptably low signal-to-noise ratios do not reach the display. Additionally, the level of noise in the displayed images is actually reduced compared with other methods that use the same strain estimates with the same level of persistence. The interface also considerably reduces the difficulty in producing volumes of strain data from freehand three-dimensional scans. (E-mail: jel35@eng.cam.ac.uk) © 2008 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Strain imaging, Freehand, User interface, Normalisation, Post-processing.**

INTRODUCTION

Ultrasonic strain imaging is an emerging technique, which is likely to have numerous applications in the clinical examination of soft tissues. In this article, we are primarily interested in the subset of elasticity imaging techniques that are categorised as “static” or “quasistatic” strain imaging (Ophir et al. 1991). In this paradigm, small tissue deformations are caused by varying pressure between the ultrasound probe and the tissue surface; two or more ultrasound frames are recorded during this deformation and some form of tracking is applied to the recorded ultrasound data to estimate tissue deformations, amounting to displacement fields that vary with position. Spatial derivatives of such a displacement field are tissue strain, which indicates stiffness; there are sometimes further stages of analysis to estimate quantitative tissue properties directly, such as elastic moduli (Kallel and Bertrand 1996). Quasistatic strain imaging was first tested clinically for breast scanning (Garra et al. 1997) and breast screening has ever since been a key driver for research (Matsumura et al. 2004; Itoh et al. 2006; Regner et al. 2006; Svensson and Amiras 2006). Numerous studies have been motivated by prostate screening (Pesavento and Lorenz 2001; Miyanaga et al. 2006). Detection and staging of deep vein thrombosis also seems particularly promising (Emelianov et al. 2002) and there are many other possible applications.

One of the engineering challenges in strain imaging is the development of a suitable clinical interface. Ultrasound clinicians have extensive experience with existing scanning modes including B-mode grey-scale, colour Doppler and power Doppler. Given the highly interactive nature of ultrasound examinations, the established modes have advantages in that clinicians are already well practised in the required scanning techniques, understand the significance of typical images, and are generally familiar with the uses, benefits and disadvantages of each mode. The likelihood of an addition to the ultrasound tool-set gaining clinical favour may be boosted if it possesses an interface that is practically helpful: actively fostering the development of a successful scanning technique, by providing either visual or audio feedback; displaying data in an intuitively meaningful format; and automatically guarding against the presentation of misleading data.

The aforementioned issues concern *how* we present information. We may also consider *what* information to present. This raises at least two further issues. Qualitatively, what type of information can be provided (stiffness, strain or an alternative compromise)? Quantita-

Address correspondence to: Joel E. Lindop, University of Cambridge, Department of Engineering, Trumpington Street, Cambridge, Cambridgeshire CB2 IPZ United Kingdom. E-mail: jel35@eng.cam.ac.uk

tively, how much data should be amalgamated to form each display image? This latter question is relevant to many types of imaging system, particularly those pertaining to time series data (where persistence may help, whether to improve a real-time display during acquisition or for post processing) and to volumetric data (where spatial averaging can be applied to reduce the level of noise).

Regarding the type of information, we note that ultrasonic strain imaging falls within a broader set of emerging elasticity imaging techniques. These are all essentially concerned with mechanical properties such as tissue stiffness, of which strain is only an indicator. Strain measurements can be converted into stiffness estimates if the stress field is known but it is highly unlikely that this can be inferred from either static or quasistatic deformation data without reducing the resolution and imposing certain limiting assumptions (Barbone and Bamber 2002). Furthermore, such assumptions are unlikely to hold even approximately under *in vivo* scanning conditions, especially not with freehand scanning. On the other hand, strain images can be misleading because an interpretation of low strain as indicating relatively high stiffness may be erroneous if the stress field varies substantially throughout the tissue (Ophir et al. 1991; Lindop et al. 2006). Some types of stress field variation occur repeatedly and can, hence, be adjusted for. We will discuss the use of strain normalisation that varies both between images and within every individual image so as to reduce the ambiguity of strain. The modified data after nonuniform normalisation are referred to as "pseudo-strain".

In practice, an often more severe obstacle in freehand strain imaging is the basic challenge of achieving an acceptable strain estimation signal-to-noise ratio. Although many frames individually produce good images, typically a substantial fraction (sometimes a majority) of frames may be difficult to interpret because of high estimation noise. One of the common approaches to noise reduction amounts to averaging a sequence of strain images (Varghese and Ophir 1996). Rather than crude frame averaging, we present a more sophisticated weighting approach, which we use for persistence in the real-time display, and for spatial averaging in the display of volumetric data (Treece et al. 2008b).

The goal of this report is to describe aspects of a novel interface that we have developed to support a wide-ranging clinical trial of ultrasonic strain imaging. The new interface tackles all of the issues mentioned above, to improve the quality of data that clinicians can acquire and to improve the interpretability of the display. We present results based on example images that demonstrate the effects of all aspects of the interface, using recorded radio-frequency (RF) ultrasound data from freehand scans of *in vitro* and *in vivo* targets.

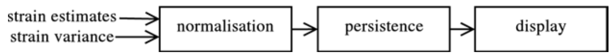

Fig. 1. Flowchart illustrating aspects of the interface that will be discussed.

METHOD

The interface that we outline here is applicable to any static or quasistatic strain imaging system, almost regardless of the approach taken in the earlier stages of signal processing. It is likely to be particularly valuable in conjunction with freehand scanning. We provide illustrations based on an example, in which displacement tracking is by weighted phase separation (Lindop et al. 2008a) with amplitude modulation correction (Lindop et al. 2007), and axial strain estimation is performed by piecewise-linear least squares regression (Kallel and Ophir 1997). This offers a good demonstration, not primarily because of its competitive estimation accuracy but more importantly because it has already been analysed and tested rigorously, resulting in a promising method for predicting the strain estimation variance (Lindop et al. 2008b, 2008c). Nonetheless, the aim of this article is to describe our interface concept in general; the reader may envisage numerous specific applications. We now provide an overview of the interface as a whole. This is followed by a brief discussion of predicting estimation precision, and descriptions of each of the three subsequent stages of processing in the interface which are normalisation, persistence or spatial averaging and display (see Fig. 1).

Interface concept

Strain image quality varies substantially depending on the sonographer's scanning technique, physiological motion in the tissue and changes in the analytical parameters for converting RF ultrasound data into strain data. In order to produce consistently meaningful images, these parameters need to be controlled locally so as to adjust for different conditions during the scan. Lindop et al. (2008b, 2008c) describe such a system. However, adjustment of parameters cannot alone overcome all of the difficulties associated with practical strain imaging. For a start, at some stage it becomes impossible to produce meaningful deformation data from frames that are extremely weakly correlated. An adequate minimum level of correlation may not always arise, depending on the scanning technique, and with a very poor technique it may not even occur often. Even in the majority of frames where a uniform estimation signal-to-noise ratio can be