Acoustoelastic Evaluation of Tissue Damage

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Background

Ultrasound is widely used in clinical settings. It can be used to detect tissue structures by measuring their reflective properties. Unfortunately with standard ultrasound, low-level tissue damage assessment is less reliable. As seen in conditions such as cirrhosis, if left untreated, progressive low-level damage can lead to a loss of tissue function. Using the property of acoustoelasticity, ultrasound can be used to diagnose such conditions.

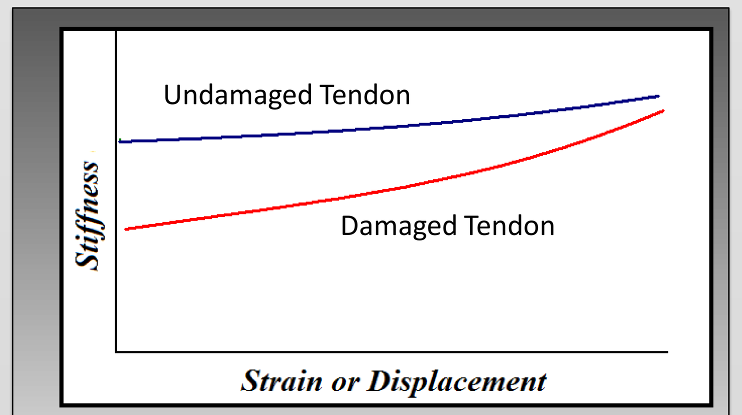
Acoustoelasticity

Acoustoelasticity uses changes in stiffness with deformation to classify tissues. An ultrasound video is taken and change in stiffness between frames is analyzed.

Stiffness is the force required for an amount of deformation
Stiffness = $k = F/\delta$

Strain is the deformation relative to the original tissue length; Strain = $\varepsilon = L/L_0$

Intensity of an ultrasound image is correlated with the tissue's stiffness



Graph of stiffness-strain relationship in damaged (red) and undamaged (blue) tendons. Borrowed from Kobayashi, et al 2008.

Damaged tissue was shown to have a lower amount of stiffness when subjected to a given deformation.

A visualized display of stiffness over strain can deliver detailed feedback over entire tissue regions to better evaluate the nature of damage.

Measuring changing stiffness vs. strain can provide functional data about tissues that operate by deforming.

Elastography, a similar technique, is aimed at detecting and classifying tumors

Sonogram Elastogram

Problem

Current ultrasound techniques can not detect low level damage which changes material properties but not structure of the tissue.

Goal

Use acoutoelasticity to obtain material properties to diagnose low-level tissue damage. Analysis should be completed in under 5 minutes.

Approach

Collaborate with Dr. Kobayashi and Dr. Vanderby to integrate an algorithm with a digital signal processor to analyze ultrasound data at high speeds to calculate the stiffness vs. strain distribution of the tissue.

Texas Instruments has donated a DSP chip that will be used for this project.

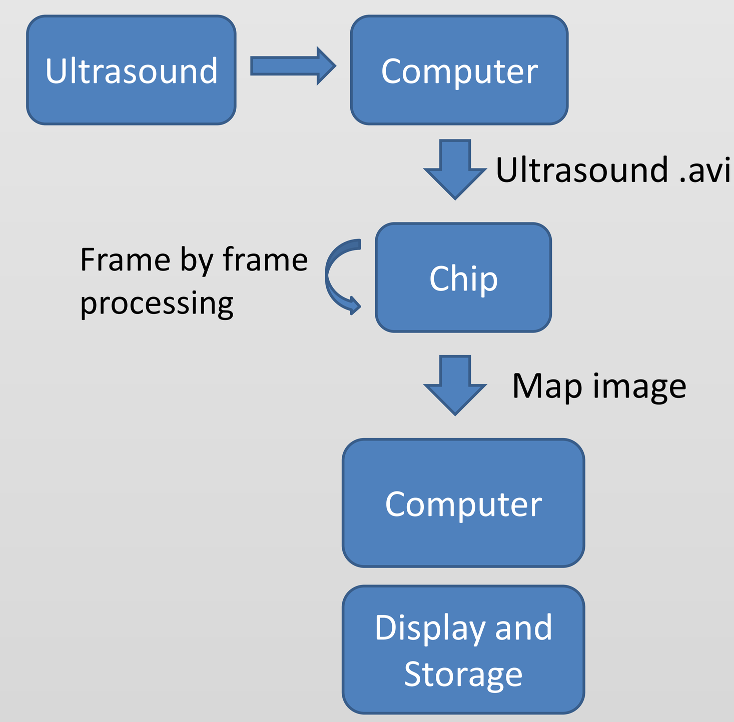
Digital Signal Processing

Digital Signal Processors (DSPs) are optimized to do simple calculations quickly, using:

- Parallel computing
- Separate program and data memories
- Simple memory management

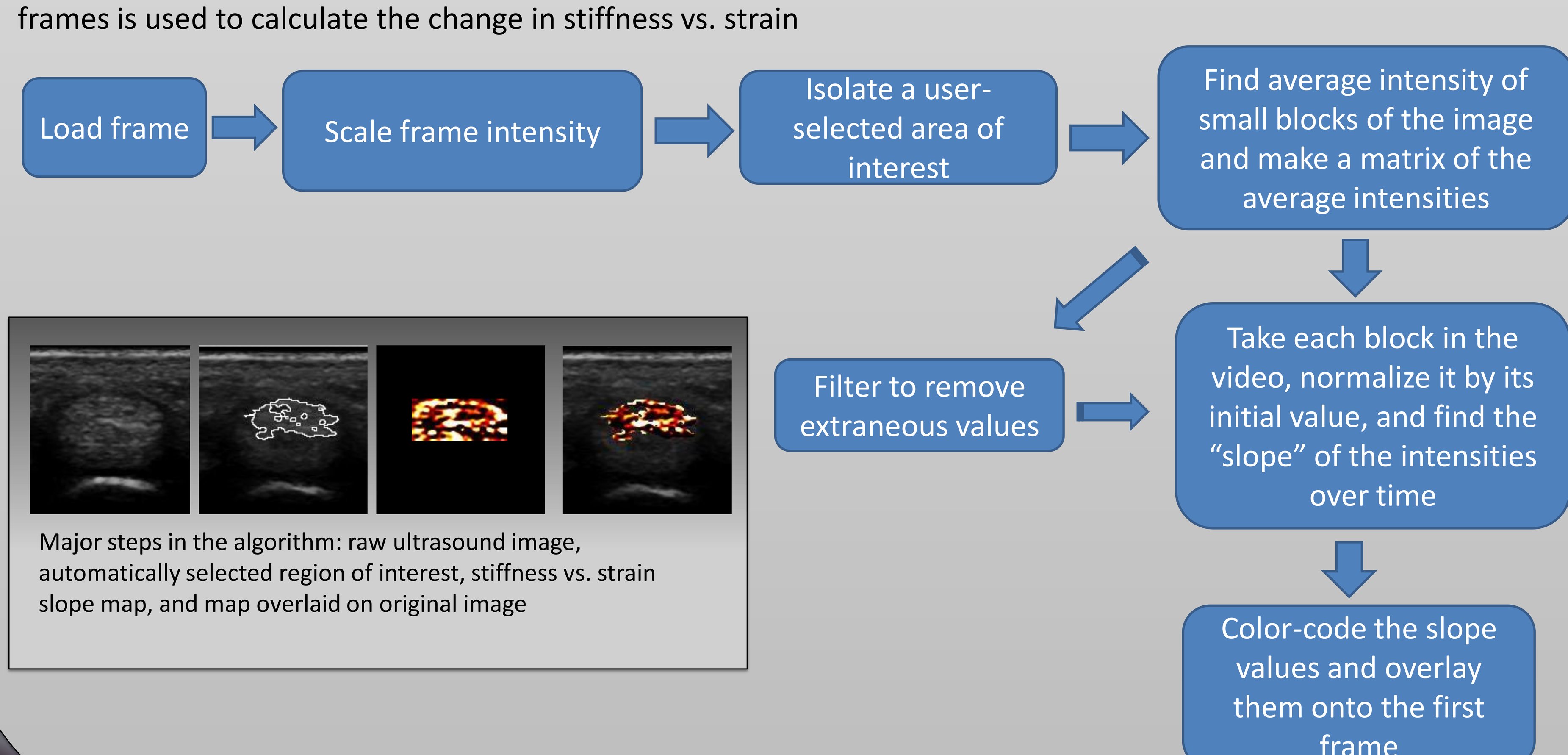
Interface

- A small program is installed on the PC for controlling the input parameters
- USB interface driver loads the program from the PC onto the chip
- A host is set up for data transfer over Ethernet
  - Sequentially sends frames to the chip for processing
  - Final image is transferred to the PC after last frame is processed
  - Intermediate data is temporarily stored on the chip's RAM



Algorithm

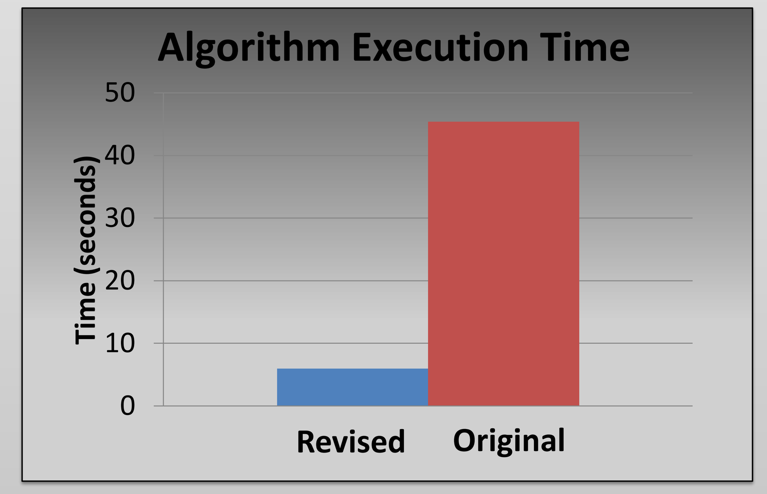
- A region of interest is selected to reduce the amount of data processing
- Processes an ultrasound video and outputs a map of the changes in stiffness during constant strain
- Small blocks of pixels are averaged in each frame to reduce noise
- Assuming constant strain rate, the change in intensity of a given block over a series of frames is used to calculate the change in stiffness vs. strain

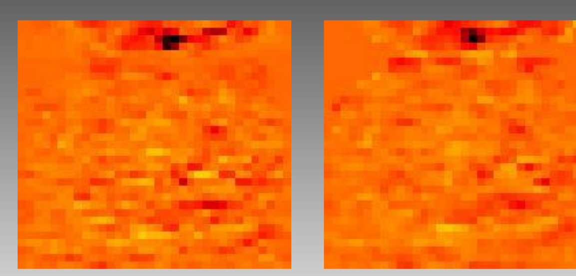


Major steps in the algorithm: raw ultrasound image, automatically selected region of interest, stiffness vs. strain slope map, and map overlaid on original image

Results

- The edge detection and stiffness vs. strain algorithms were integrated
- The algorithm was optimized reducing execution time without introducing significant data deviation (5.9% deviation in calculated intensity)
  - Block segmentation and averaging were replaced with convolution
  - The number of "for" loops was reduced





Output of revised (left) and original (right) algorithms. Intensity represents slope of stiffness vs. strain

Interface

- Used example source code, written in C, from Texas Instruments as a template to create an Ethernet interface
- Movies can be read from the PC frame by frame

Future Work

Software

- Employ three-dimensional structures to reduce the number of "for" loops and increase speed
- Remove edge effects of averaging
- Improve filtering
- Continue testing and refining

Compatibility

- Combine interface and analysis algorithms
- Convert analysis algorithm from Matlab to C by hand or using Simulink

Interface

- Expand user control program on the PC for adjusting region of interest and filter settings
- Set up server to read multiple frames from the hard drive simultaneously to reduce read/write time
- Possibly add more on-board RAM to the chip to increase the number of stored frames

Acknowledgements

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References

Foucher J *et al.* 2006. Diagnosis of cirrhosis by transient elastography (FibroScan): a prospective study. Gut, 55(3):403-8

Kobayashi, H. and Vanderby, R.,2005, "New Strain Energy function for Acoustoelasticity Analysis of Dilatational Waves in Nearly Incompressible Hyper-Elastic Materials," J. Applied Mech.,Vol.72, pp.843-851

Kobayashi, H. and Vanderby, R., 2007, "Acoustoelastic analysis of reflected waves in nearly incompressible, hyperelastic materials: Forward and inverse problems," J. Acoust. Soc. Am., Vol.121 (2), pp.879-887

Pourcelot, P., et al. "A non-invasive method of tendon force measurement." J of Biomech 38.10 (2005): 2124-29.

Pislaru, C., *et al.* 2004. Ultrasound Strain Imaging of Altered Myocardial Stiffness. Circulation. 109:2905-2910