Seminar report
Group 6: Thermal Imaging
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Mentors: Dr. Emad Boctor, Younsu Kim

1.Paper selection:

[1]Techavipoo U, Varghese T, Chen Q, et al. Temperature dependence of ultrasonic propagation speed and attenuation in excised canine liver tissue measured using transmitted and reflected pulses[J]. The Journal of the Acoustical Society of America, 2004, 115(6): 2859-2865.

Paper description
This article describes how to collect data of speed of sound and attenuation ratio change and inspires us to do thermal imaging with this property
[2] Kim Y, Audigier C, Ellens N, et al. A novel 3D ultrasound thermometry method for HIFU ablation using an ultrasound element[C]//2017 IEEE international ultrasonics symposium (IUS). IEEE, 2017: 1-4.

Paper description
This article describes the way to do thermal imaging with HIFU(High Intensity Focused Ultrasound)
[3] Kim Y, Audigier C, Ellens N, et al. Low-Cost Ultrasound Thermometry for HIFU Therapy Using CNN[C]//2018 IEEE International Ultrasonics Symposium (IUS). IEEE, 2018: 1-9.

Paper description
This paper describes how we can do thermal imaging with deep learning.

2.Paper I

2.1 Importance:

- The ultrasound thermal monitoring is possible using ultrasound physics : SOS(Speed of Sound) and attenuation changes with temperature
- It provides more accurate way to plot SoS versus temperature, which can be helpful to conduct experiments
- It shows attenuation coefficient works only in some specific cases. Thus, we should rely more on SoS.

2.2 Problem and goal

Problem

- Previous SoS(Speed of Sound) change and Attenuation coefficient measurements are in little change on temperature 20-50 celsius degree
- Measurement of SoS and Attenuation coefficient are not conducted simultaneously
- Tissues are used repetitively which result the cumulative degradation of the tissue structure

Goal

- Measure data in wide and high temperature range

2.3 Technical Approach

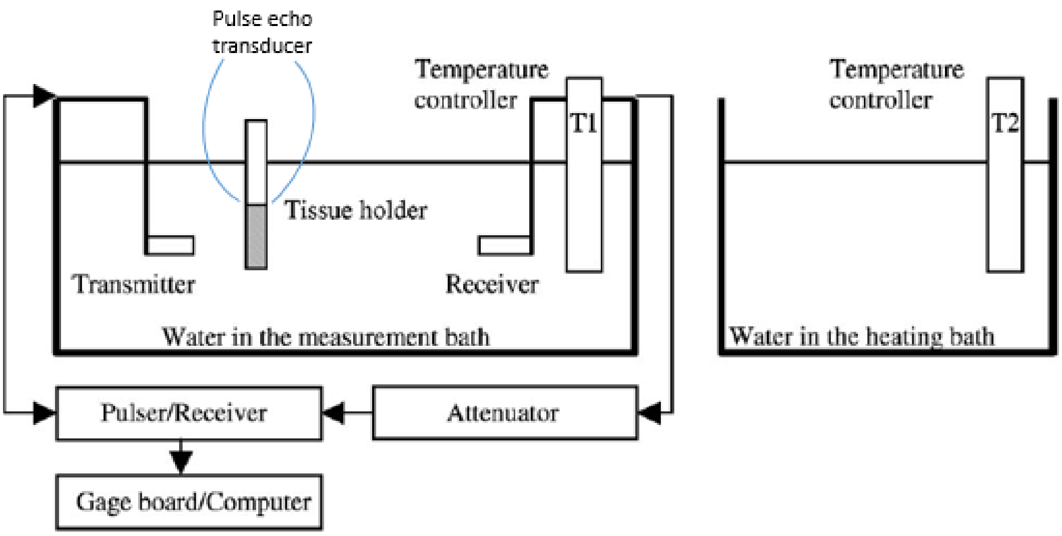

Figure 1

- Tissue are heated in the heating bath and test in measurement bath
- Signal was transmitted through a tissue sample positioned within a tissue holder and received by a second transducer.
- Ultrasound echoses from interfaces were detected by pulse echo transducer
- Time of transmitting and receiving are collected as well as amplitude

2.4 Conclusion and result

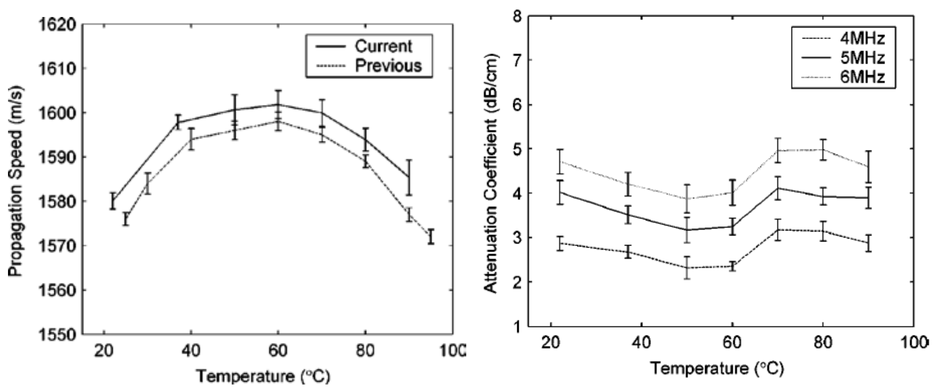

Figure 2

SoS

- Plots of mean propagation speed were measured at different temperatures compared to the previous result.
- Note that error bars are plus and minus one standard error across different samples

Attenuation coefficient

- Attenuation coefficients were measured at different temperatures for frequency of 4,5 and 6 MHz

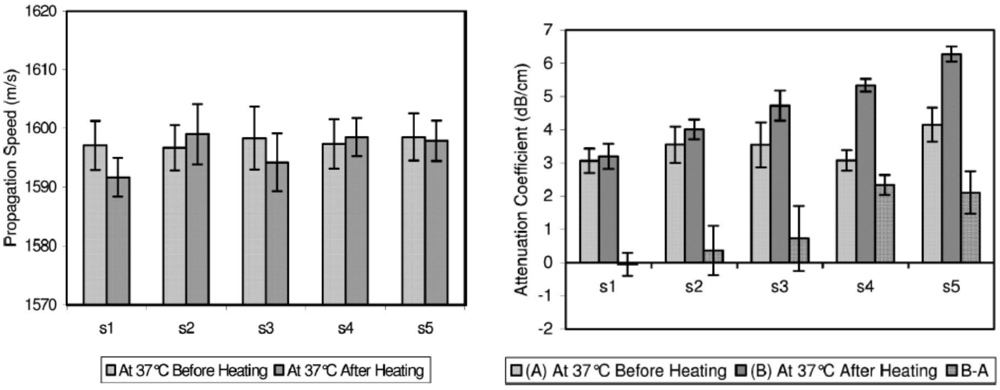

Figure 3

SOS

- Bar plots comparing the SoSin canine liver tissue measured at 37 °C before and after the tissue samples were heated to the elevated target temperatures.

Attenuation Coefficient

- Bar plots comparing the attenuation coefficients in tissue measured at 37 °C before and after the tissue samples were heated to the elevated target temperatures.

2.5 Good and bad

Good

- The paper consider the property of tissue may change the SoS and attenuation coefficient
- The paper made a comparison with graph to show SoS is a better parameter which is clear and convincing
- The bar plots are clear to show all information and relationship between experiments

Bad

- The article does not clarify the challenage of measurement in large and high temperature range as well as the specific solution
- The picture is not complete and the article does not clarify the function of Attenuator
- No ground truth is provided

2.6 Inspiration

- We can make full use of change of SoS to design the network and monitor the temperature change in HIFU experiment
- The initial status before ablation is important information to measure the temperature thus the network should include the initial status

3.Paper II

3.1 Importance

- It provides a novel method and experiment to generate temperature image from ultrasound signals.
- It provides the derivation of generating temperature from collected time of flight, where the network can learn from.

- It provides SoS versus temperature which can be reference.

3.2 Problem and goal

Problem

- Using MRI to monitor temperature is expensive and not portable
- Some people feel uncomfortable in MRI room

Goal

- Design a novel method for HIFU monitoring with ultrasound signal

3.3 Technical Approach

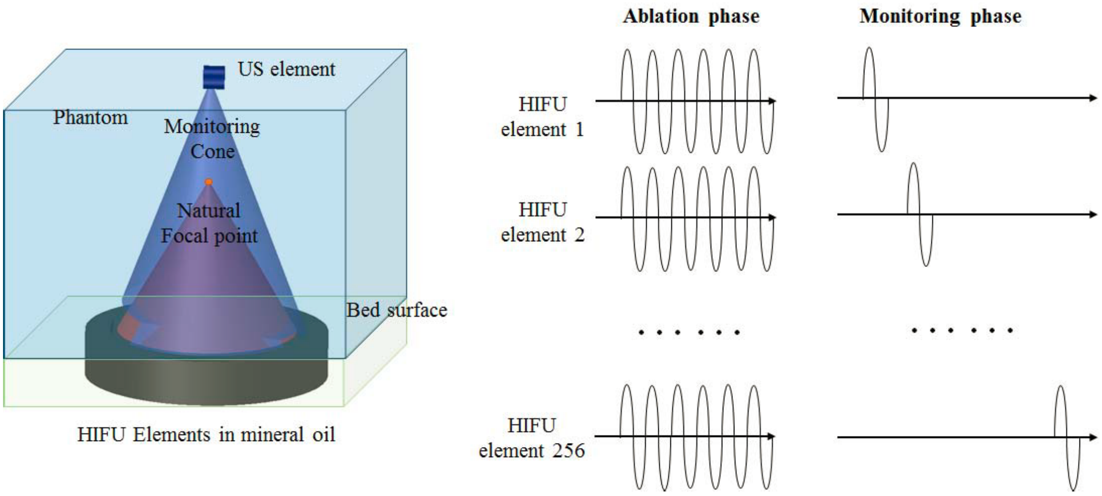

Figure 4

- 128 US elements transmitting US pulses in heating phases and monitoring phases
- The pulses going through ablation zone and propagating to the opposite where TOF(Time of Flight) is collected.
- Using TOF and position of elements to derive the temperature

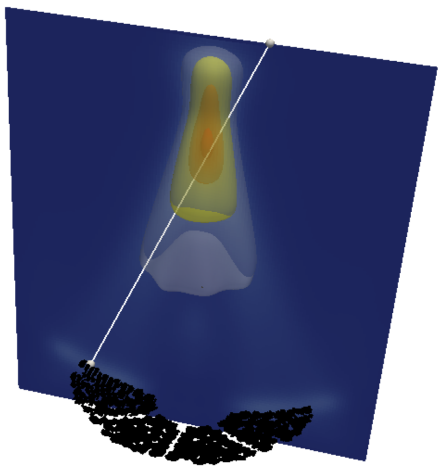

Figure 5

In order to know the position of the receiver with respect to HIFI element, we derive it with least square solution.

$$\boldsymbol{minimize_p} \sum_{n=1}^{N} (\|\boldsymbol{p} - \boldsymbol{h_i}\| - \boldsymbol{SoS_0.TOF_i})^2$$

-- p Position of the receiver

-- $\boldsymbol{h_i}$ Position of the ith HIFU element

-- $\boldsymbol{SoS_0}$ The speed of sound in room temperature

-- $\boldsymbol{TOF_i}$ Time of Flight of ith HIFU element

After know the position, we know the length and intersection lengths of traversing paths through each voxel. Then we derive the SOS of each voxel by following least square solution.

$$\begin{aligned} &\mathit{minimize}_x && \|Sx - TOF\|^2 \\ &\mathit{Subject\ to} && A_{ineq}.x \le b_{ineq} \\ & && A_{eq}.x = b_{eq} \\ & && \frac{1}{max(SoS)} \le x \le \frac{1}{min(SoS)} \end{aligned}$$

--S The intersection lengths of traversing paths through each voxel in the ROI(Reagion of Interest)

--x Inverse of the local SOS in each voxel

$A_{ineq}.x \le b_{ineq}$ *shows the TOF of inner layer is smaller of TOF of outer layer*

$A_{eq}.x = b_{eq}$ *shows the TOF of same layer is equivalent*

$\frac{1}{max(SoS)} \le x \le \frac{1}{min(SoS)}$ *shows the range of SoS*

3.4 Conclusion and result

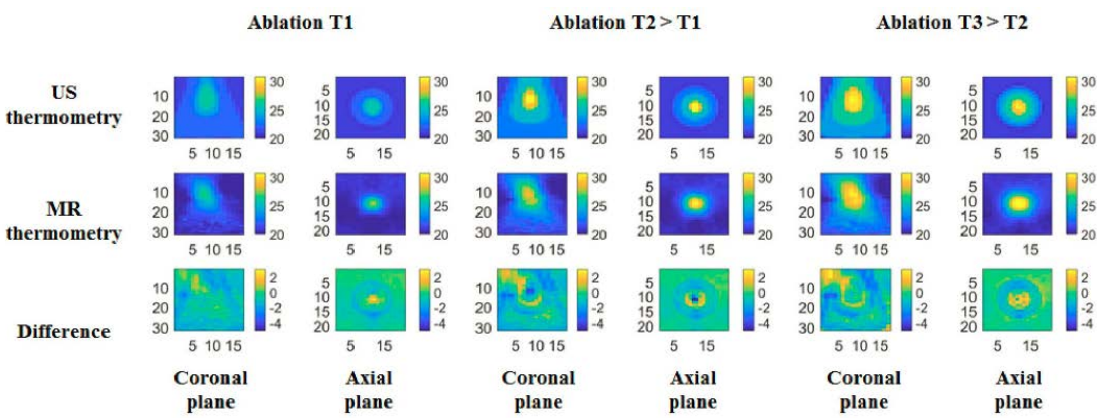

Figure 6

- Coronal and axial images at three increasing ablation times are generated.
- The temperature in ROI in coronal plane was 1.1,1.3 and 1.3 Celsius degrees on average with a maximum difference of 3.0,4.1 and 3.8 Celsius degrees.
- The monitoring phase is too long and averaging them provides less accurate information.
- The location of ultrasound elements affects the monitoring accuracy. The result could be further improved by adjusting the location of the elements. The number of elements could be increased.
- The method is novel and proved to be feasibility.

3.5 Good and bad

- Good
- Discussion part is very inspiring and proposed a lot of method to improve the result and

experiments.

- The paper clearly shows how the SOS image is generated mathmatically.

Bad

- The paper only shows the result of one experiments. More experiments results and analysis are preferred.
- The notation of how to reconstruct SOS image is not clear. $\boldsymbol{A_{ineq}}$is not clarified.

3.6 Inspiration

- Number of elements can be increased to provide more useful information.
- Position of elements can be changed to be generalized.
- The initial status is provided to network to learn position of elements and SoS of background.
- The temperature image can not only be determined on current information since SoS will first increase then decrease as temperature increases.\

4.Paper III

4.1 Importance

- It provides idea of collecting data by simulation, which will significantly improve data size.
- It provides reasonable structure of deep learning like image reconstruction.
- It provides some experience and skills to design the network.

4.2 Problem and goal

Problem

- Due to few element number, the collected TOF is sparse
- Temperature image accuracy depends highly on element location

Goal

- Design a CNN(Convolutional Neural Network) with data from simulation

4.3 Technical Approach

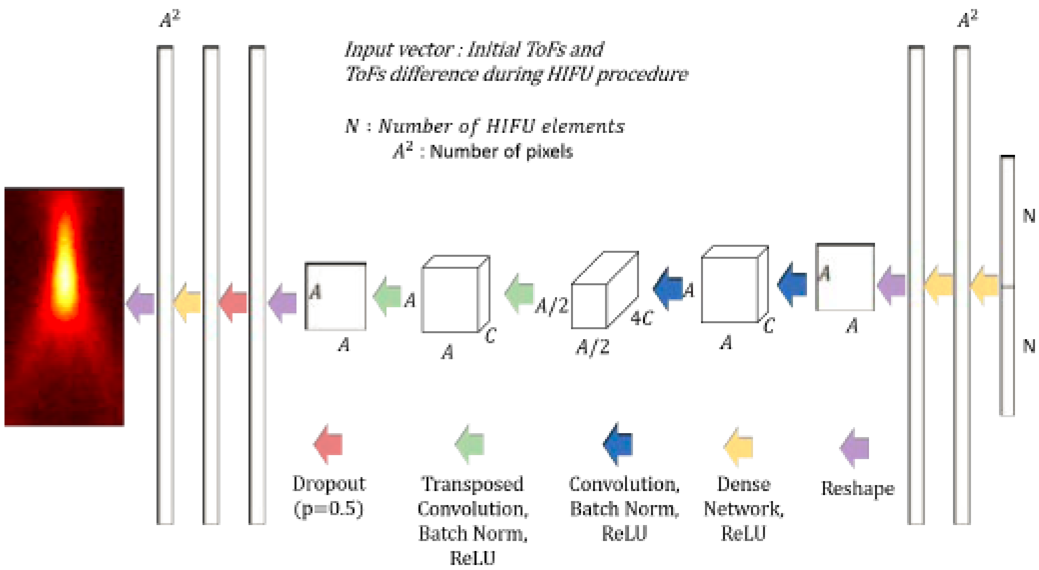

Figure 7

- The input for the network is a concatenated vector of the ToF acquired before ablation and the ToF shifts during HIFU procedure.
- TOF shift is amplified since it is too small compared with TOF.
- Ground truth is the MRI image.
- Several fully connected layers expands the input to match the output size.
- Convolutional layer and transposed convolutional layer is to extract features and reconstruct image.
- Learning rate is 10e-4

4.4 Conclusion and result

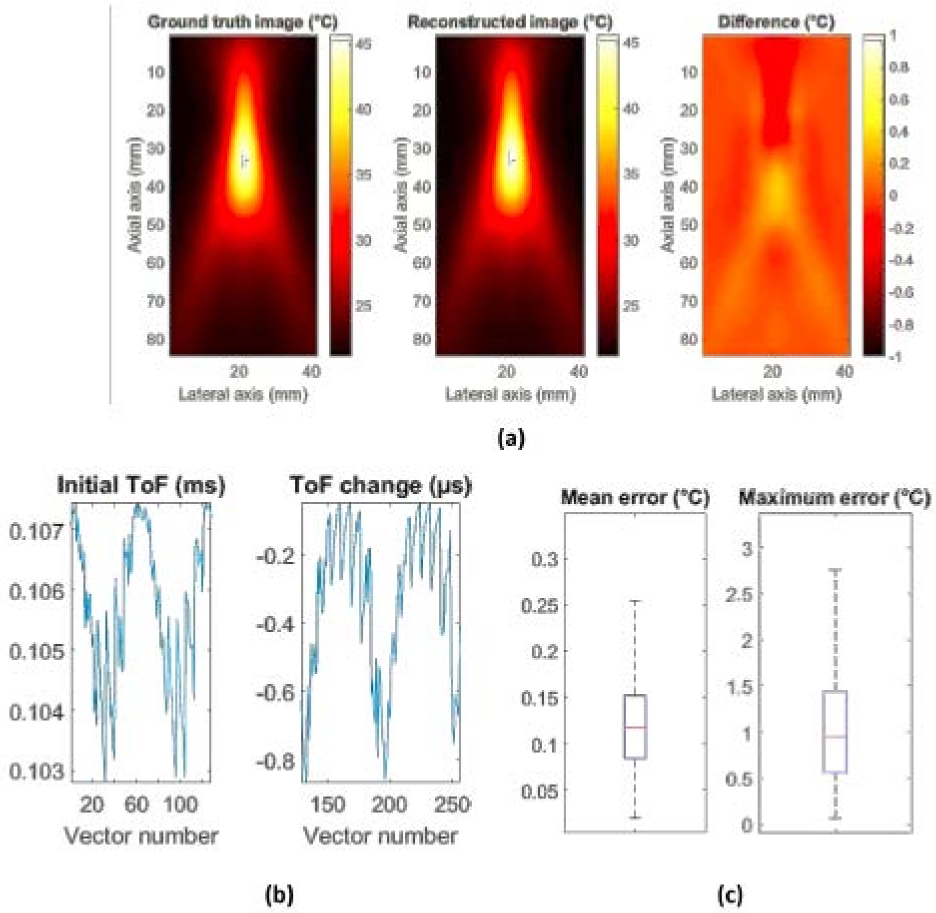

Figure 8

$0.12 \pm 0.06°C$ mean errors and $1.05 \pm 0.61°C$ maximum errors between the reconstructed images and the ground truth images.

The worst case was a reconstructed image showing a maximum difference of 3.22 C.

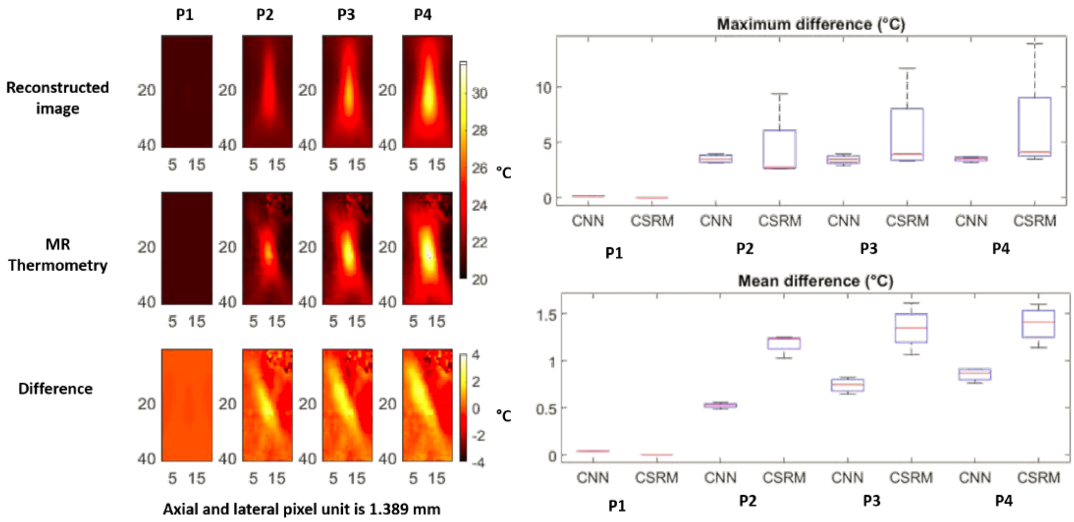

Figure 9

Deep learning method and CSRM method are compared. Four different locations of external element and their performace are recorded as P1,P2,P3,P4

4.5 Good and bad

Good

- Illustrate the structure of network and the function of each layer.
- The result of deep learning network and previous method is compared within different location of ultrasound element which helps to generalization.

Bad

- The paper does not clarify the reason why the TOF shift is included in the paper and the two phases of shift.
- The paper does not clarify what parameters are included in simulation.

4.6 Inspiration

- Image reconstruction can be used in the design of deep learning network to extract features and generate image.
- Due to limition of data, the network is highly possible to overfit. The network should prevent it.
- More data can be acquired in simulation. However, simulation data is not robust to noise.
- Part of input can be amplified if they are too small.
- In this approach, it uses time of flight only. If we use the entire channel data, then we may reconstruct more accurately with real data.