Ultrasonic Thermometry

Charles D. Holmes

Supervised by R. Martin Arthur

Department of Electrical and Systems Engineering
Washington University in St. Louis

Fall 2010—Spring 2011

Background

Research has proven that it is possible to estimate temperature from body non-invasively by observing changes in backscatter energy in an ultrasonic image of the tissue [1]. Past research has shown that this form of temperature estimation is possible from normal body temperature (37°C) to 60°C. Our overall goal was to contribute to the extension of this research such that it temperature estimation would be possible up to 70°C. To contribute to this research, the purpose of this work was to modify MATLAB code to be capable of data acquisition for synchronous temperature measurements and ultrasonic imaging from 36°C to 70°C. In addition to modifying the code, the design of the experiment was also modified to more efficiently produce results.

Experimental Setup

The methods of this work involved the measurement of temperature and synchronous ultrasonic imaging of tissue in a water bath. The tissue was usually a piece of turkey purchased from a local grocery store or a piece of preserved rabbit liver. The tissue was placed in experimental housing as seen in Figure 1. This housing was then placed in a water bath in an insulated container, as seen in Figure 2.

There are four main components to the experiment, all of which interface with each other via a MATLAB script. The components include:

1) The DATAQ, which acquires temperature data

2) The ThermoHaake, heats and circulates the water bath

3) The ultrasound transducer, which acquires ultrasonic images of the tissue

4) The Newport, which is a mechanical actuator which moves the ultrasound transducer so it can take pictures of multiple slices of tissue.

The DATAQ, ThermoHaake, and Newport are all named after the makes or models of the device.

The DATAQ and Temperature Data Acquisition

Seen in Figure 2 are thermocouples inserted into the tissue. A clearer view of the thermocouples can be seen in Figure 3. These thermocouple attached to a DATAQ device, seen in Figure 4. This device is used to acquire temperature data from multiple (up to 8) channels via thermocouple. This acquisition is done via interface with a computer program called Windaq. Windaq produces plots of temperature versus time for the given channels of the DATAQ. Windaq must be running for the MATLAB script to interface with the DATAQ.

Figure 1: The tissue placed in it experimental housing

Figure 2 - The housing placed in the heated water bath

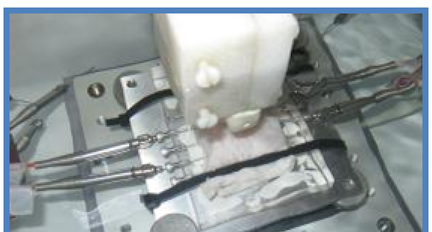

Figure 3 - The housing placed in the water bath with a clear view of the thermocouples

Figure 4 - View of the Dataq

Figure 5 - Overview of the Experimental Setup

The ThermoHaake, Water Heating, and Water Circulation

A second device used in the experiment is the ThermoHaake (the device with the screen as seen in Figure above). This device has 3 purposes:

1) Heat the Water Bath

The water bath is heated by heating coils on the underside of the ThermoHaake. This heating system is used to bring the water temperature from 36 degrees Celsius to 70 degrees Celsius.

2) Circulate the Water

The water bath is circulated by a pumping filtration system. In the same complex as the heating coils are an incoming and an outgoing pump. This system takes up water from the bath, filters the water, and then deposits the water back into the bath. This mechanism circulates the bath such that the water is in constant motion. By circulating the water, the ensures that the water bath heating will be very nearly uniform.

3) Measure the Temperature of the Water

The water bath temperature is measured by a third component of the complex under the ThermoHaake. This device is a thermistor that measure the sample of water below the ThermoHaake, but this sample is treated as representative of the entire water bath, especially because of the circulation. The thermistor is also treated as the "truth" for temperature measurement, that is to say that it is treated as having zero error in its measurement.

This system measures the temperature in the tissue from 4 different channels and at the same time measures temperature from two points in the water bath. The two points outside of the tissue are the space directly beneath the ThermoHaake and the space on the opposite end of the insulated container. These temperature measurements are to observe any temperature gradient in the water.

MATLAB commands that interface with the ThemoHaake can be seen here.

The Ultrasonic Transducer

The ultrasound transducer is used to take images of the tissue in the area of the four thermocouples in the tissue. In the end, the research this experiment is contributing to will find the correlation between these images and the temperature measurements in the tissue at the time of the image. The transducer interfaces with a computer program called Terason. Terason is a user interface that allows for easy use of the transducer. MATLAB calls the Terason to open and take ultrasonic images of the tissue. This images are saved in a directory on the computer.

The transducer can be seen in figure 2, 3, and 5. It is the white block shaped object above the tissue.

The Newport

The Newport is a mechanical actuator which moves the ultrasound transducer with respect to the tissue. This is done so that multiple images can be acquired for multiple slices in the tissue. The Newport interfaces directly with MATLAB.

The Methods

This section will go over the procedure of the experiment. This section also functions as a user's manual for running an experiment.

Step 1: Setup

To start, the tissue must be cut to fit in the experimental housing. This is best done with a pair of scissors. After it is cut, it is placed in the housing and the housing is placed in the insulated container.

A series of filters and a degassing vacuum are used to deionize and degas some water. The water is used to fill the container. On the underside of the ThermoHaake is a float. The proper amount of water to use in filling the container is enough water to lift the float. Without lifting the float, the ThermoHaake will not function.

Step 2: Initialization

From a MATLAB terminal, the user calls a MATLAB script. For this particular experiment, the script was called "Therm3d_sdk_cdh.m".

For the most part, this first step involves initializing and calibrating the various devices associated with the script. At most parts of this first step, the script will prompt the user to press any key when the initializing action is complete.

Windaq and the DATAQ: Part 1

The script will start up the Windaq software.

The script will ask the user to press any key when Windaq is running. When a key is pressed, the script will proceed.

Header File

Associated with each experiment is a header file (.HDR), which contains all the experiment's parameter information. Examples of parameters contained in the header file include

- Experiment name
- Temperature Set (the temperature that will be observed over the course of the experiment)
- Numbers of Channels to be used for temperature measurement

The script parses the header file and sets script variables to be equal to header file parameters.

ThermoHaake

The ThermoHaake pump speed is set to an appropriate value (for now it is a hard-coded value of 50). Then the water is circulated with no heating. This is accomplished by setting the target temperature (or temperature to be heated to) to 10 degrees Celsius and pumping the water. The water is pumped to ensure that the there is little to no temperature gradient in the water for the rest of the initialization process.

Windaq and DATAQ: Part 2

Callibrating the Thermocouples

The script will ask the user to place all the thermocouples under the ThermoHaake thermistor and verify that they are there with a key press. For each thermocouple, a temperature measurement will be made. Then the thermocouple measurement system will be modified to match the ThermoHaake thermistor. This is done by observing the equation

$$y = mx + b$$

where y is the temperature output of the system (or the measurement), x is the temperature input (or the actual measurement of the thermocouple), m is the slope which is a parameter of the thermocouple, and b is the offset which is determined by this part of the experiment.

The slopes are predetermined and saved as mat-file (in this case as TCSlopes.mat). The script loads the mat-file and passes the values into further calculations.

The offset is determined by the shifting of the previous equation to be

$$b = y - mx$$

We know x and m. If use the ThermoHaake thermistor measurement, which we treat as the actual temperature of the water, as our y value, then we can solve for b.

Thermocouple Placement

The script then asks the user to place the thermocouples in their experimental positions. One thermocouple is placed directly below the the ThemoHaake. Another thermocouple is placed on the opposite end of the insulated container. The remaining four thermocouples (6 in total are used) are placed in the tissue.

The user will be prompted to verify when this is done.

The Newport and the Ultrasound Transducer

The script will ask the user if the Newport turned on. When it is turned on and a key has been pressed to verify that it is on, the script will proceed.

The Newport will then move the transducer from one end of the tissue to the other. All this time, the ultrasound transducer is taking images of the tissue. The user can use this "scan" as an opportunity to verify that the transducer is placed right, the thermocouples are in the view of the image, etc.

For a view of the Terason user interface, see Figure 6. The upper left corner shows the Terason's ultrasound image viewer.

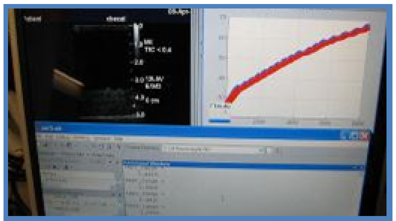

Figure 6 - A typical view of the computer screen during an experiment. In the upper right is the plotted data. In the upper left is the Terason user interface. This interface shows the current image form the ultrasound transducer. The bottom show the MATLAB

Step 3: Heating the Water Bath and Data Acquisition

Heating the Water

The ThermoHaake will begin an iteration that heats the water bath to temperature values in the temperature set parameter. For each temperature in the set, the ThermoHaake will heat and circulate the water bath until the temperature is reached. For this part of the process, the ThermoHaake will set the target temperature to be half a degree larger than the true target temperature.

As the temperature of the water approaches target temperature, the system will repeat three steps. First, the system will acquire the temperature measurements from all the thermocouples and the ThermoHaake thermistor. Then the MATLAB script will plot these values against the time they were observed. An example of a plot can be seen in Figure 6 in the upper right corner. The red data represents measurements made in tissue and blue data represents measurements made in the water. Finally, the script will archive the temperature measurements by concatenating the values to a matrix. At the end of the experiment, these matrices will be saved.

This sequence of events repeats until a the target temperature is reached. When the true target temperature is reached, the ThermoHaake target temperature will be set to 10 degrees Celsius so that while circulation can continue in the water, heating cannot occur. This is to facilitate the tissue reaching a temperature equilibrium. At this point, the script enters a sub-iteration in which temperature measurement, plotting, and archiving still occurs as before. This will continue until a temperature equilibrium is reached.

Equilibrium is reached when the difference between the greatest thermocouple measurement and the the least thermocouple measurement is less than a equilibrium constant, which has a value determined by a header file parameter.

Data Acquisition

If an equilibrium is reached, then images are taken at different slices of the tissue. If an equilibrium is not reach in a certain time, determined by a header file parameter, then imaging occurs as though equilibrium had been reached. These images are then saved in the "ult" directory in the experiment directory. The images are saved with the name "(experiment ID)_(temperature)_(slice number)".

After the images are taken, the archived matrices are saved in a mat-file named "(experiment ID)exp.mat".

After every temperature has been visited, the "ult" directory will contain the pictures from every slice for every temperature. Figure 7 shows slice 15 at increases temperatures. Notice how it appears to rise. This is because increased temperature in the water allows for faster propagation of the ultrasound.

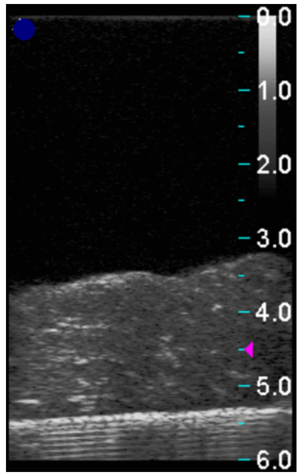

Figure 7 - Slice 15 at increasing temperatures

Haake Commands

haakeGo_cdh(s)

This command starts the ThermoHaake pumping and heating. The passed variable s is the handle of the ThermoHaake.

haakeStop_cdh(s)

This command stops the ThermoHaake pumping and heating. The passed variable s is the handle of the ThermoHaake.

haakePumpSpeed_cdh(s, speed)

This command changes the pump speed of the ThermoHaake to the value speed. The passed variable s is the handle of the ThermoHaake.

haakeSetTmpr_cdh(s, tmpr)

This command changes the target temperature of the ThermoHaake to the value tmpr. The passed variable s is the handle of the ThermoHaake.

haakeGetThermistorTmpr_cdh(s)

This command return the value of the ThermoHaake's current thermistor measurement. The value returned has units of degrees Celsius. The passed variable s is the handle of the ThermoHaake.

References

[1] R. M. Arthur, D. Basu, Y. Guo, J. W. Trobaugh, and E. Moros, "3D In Vitro Estimation of Temperature Using the Change in Backscattered Ultrasonic Energy", IEEE Trans. on UFFC, vol. 57, no. 8, pp. 1724-1733, 2010.