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Parameterized Computational Imaging: Data Driven Computational Modeling for Image Extension

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Abstract— **Parameterized Computational Imaging (PCI) allows for a continuous, portable and remote imaging of physiology without the continuous need of complex imaging systems. The method trades complex imaging equipment for computing power and potentially wireless measured parameters. The PCI algorithm uses a baseline image along with computational models to calculate physically measurable parameters. As the physically measurable parameters change the computational model is iteratively run until computationally predicted parameters matches the measured values. Swarm optimization routines are implemented to accelerate the process of finding the new values. A gelatin model with circular object is presented to demonstrate the PCI algorithm's ability to locate the circular object from four voltage measurements.**

I. INTRODUCTION

Parameterized Computational Imaging (PCI) provides a method to extend a high resolution image, such as an MRI or CT Scan resulting in continuously updating high resolution images. PCI relies on advancements in several different technology areas, including including computer power, image segmentation, wireless technology, sensor fusion, database systems, and multiphysics and time varying computational models.

This paper presents a gelatin experiment utilizing the parameterized computational imaging algorithm. The presented gelatin experiment demonstrates and validates the PCI algorithm by 1) showing that modeling alone can generate accurate results and 2) modeling with optimization routine (Particle Swarm Optimization in this case) can localize to the desired image. Moreover, this is the first time that Particle Swarm Optimization has been used with the PCI algorithm in a physical (non-simulation) case. Thus, the presented experiment is a significant step towards validating the PCI algorithm.

II. PCI ALGORITHM

Parameterized Computational Imaging provides a technique for obtaining high quality, portable and continuous images through a baseline image and measured physiological data. Figure 1 shows a flow chart of PCI with emphasis on the baseline image and measured physiological data.

The PCI algorithm begins with the baseline image (taken from MRI, CT scan or other high resolution imaging system) which is segmented and input into the computational model. This temporary image is processed using a finite element method computational model. The computational model will output predicted data values that match measured data depending on the mathematical equations used in the model.

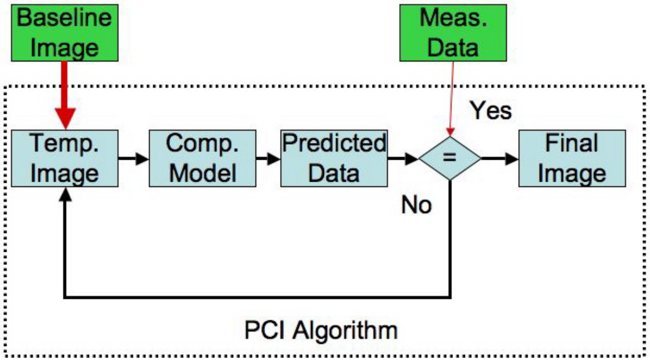

Fig. 1. PCI Flowchart

The predicted data is compared to the measured data to see if the two are within acceptable tolerance for the specific application. If the measured and predicted data are equivalent then the temporary image is used to create a final image. If the measured and predicted data are not equivalent then the temporary image is modified and the computational model is run again. A optimization routine helps speed up this process by adjusting the temporary image based on the difference between the measured and predicted data.[2]

III. EXPERIMENTAL SETUP

To help demonstrate and validate the PCI algorithm an experiment was set up using a square gelatin filled container with a circular cut-out in one corner. The purpose of this experiment was to create a homogeneous medium with a circular cut-out and see if it was possible to identify the general quadrant of the circular cut-out in the medium. Although there are several applications that could be derived from this experiment, the main benefit of this experiment is to show the PCI algorithm working in an actual physical experiment with the attendant problems created by real world noise.

To accomplish this a square plastic container with six aluminum tape ”electrodes” was filled with a gelatin/salt/water solution. A circular hole was then placed in one of the four quadrants by using a cookie cutter to remove a circular section of the gelatin as shown in Figure 2. A sinusoidal current was then applied to the gelatin and the voltage measured at the aluminum tape electrodes.

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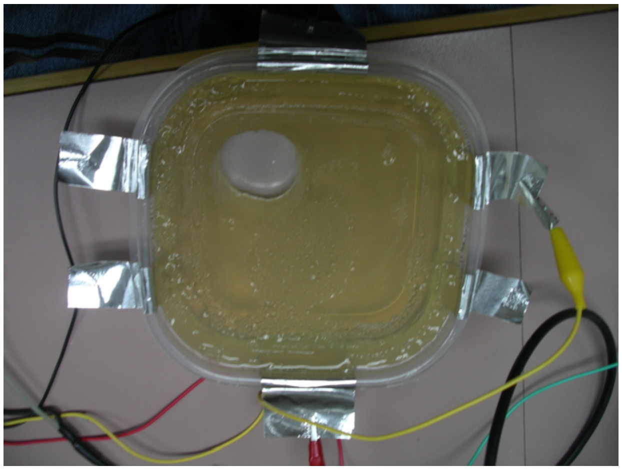

Fig. 2. Picture of the square gelatin container with circular cut-out

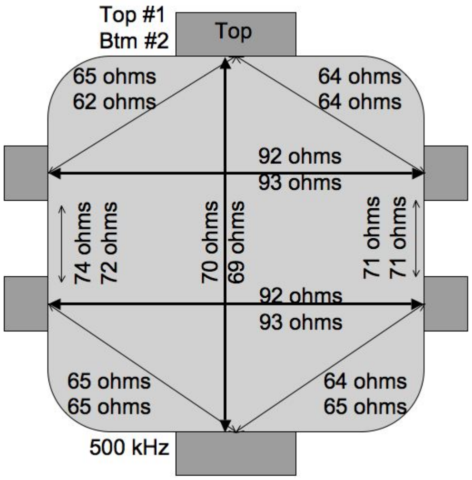

Fig. 3. Resistance (in Ohms) of the gelatin mixture for the two containers

The square plastic container has a square width of 5 3/4 inches (14.6 cm) and a depth of two inches (5.08 cm). Adhesive aluminum tape (used for ducts) with a width of 1 7/8 inches (4.7625 cm) was attached to the inside of two opposite walls of the plastic container with the aluminum tape running down the entire inside of the container leaving a flap hanging over the edge of the container (each piece of aluminum tape was about 3.5 inches long) used to attach alligator clips to a function generator and oscilloscope. Aluminum tape sliced in half was applied to the remaining two sides of the plastic container 1 1/4 inches (3.175 cm) from the sides of the container. Two plastic containers with aluminum tape electrodes were created using these dimensions.

A gelatin mixture was made using 1.5 liters (L) of distilled water, 132 grams (g) of gelatin, and 3/4 teaspoon of non-iodized salt. The ingredients were mixed together in hot water and then poured into the two plastic containers (each container holding 750 mL of gelatin mixture) and covered with a plastic lid. The mixture was then allowed to cool and gelatinize at room temperature.

To validate the homogeneity of the gelatin mixture in both containers, the resistance of the mixture in each container was measured using a 500 kHz sinusoidal current. As shown in Figure 3 there is very little difference between the containers and very little difference between similar measurements. The top number represents container #1 and the bottom number represents container #2. There is a 0.3 ohm resistance from the cables and equipment. Some of the difference in resistance can be accounted for in the lack of precision as a result of cutting and placing the aluminum tape ”electrodes”.

To account for lack of precision in the electrodes the first step in the PCI algorithm is to calibrate the computer model to compare against the actual experimental results. This is a key step in the PCI algorithm for it is always assumed that the initial conditions of the image are known as well as the initial parameters. For this experiment a function generator was used to produce a 20 volt peak to peak 500 kHz sine wave across the two full width electrodes. Since the function generator has a built in resistance of about 30 - 50 ohms the resulting impedance across the gel will be in the 11 - 12 volt range. As shown in Figure 4, the applied voltage was 11.3 volts for both containers.

An oscilloscope was used to measure the peak to peak 500 kHz voltage from each of the four measurement electrodes to the right electrode as presented in Figure 4. The first value is the first plastic container voltage measurements and the second number is for the second plastic container. The third value is the voltage measurement after adjusting the width of each one of the electrodes in the computational model.

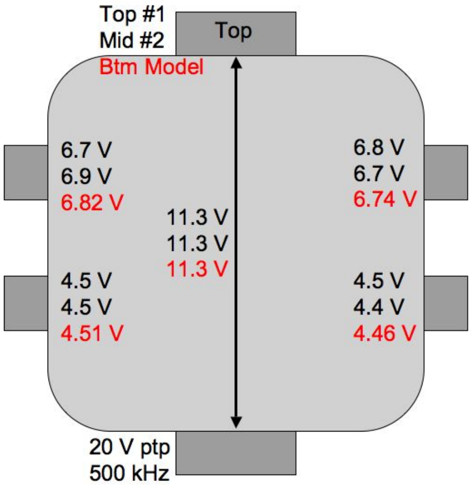

Fig. 4. Voltage measurements of container with no circular hole

IV. COMPUTATIONAL MODEL SETUP

A computational model was setup representing the plastic container and electrodes. Similar to the circular models presented earlier in this Section, the quasi static AC current equation[1] is used in this model to represent the flow of current through the gelatin in the plastic container. The boundaries were set as non-conducting with an electric potential applied between the two full width electrodes that matched the experimental applied voltage. The electric conductivity of the gelatin was set at 0.08 S/m.

The measured electrode voltages were derived by integrating the electric potential along the boundaries representing the electrodes and then dividing by the width of the electrode. The model was initially setup with no circular hole, representing the homogeneous gelatin mixture in the plastic container. The computational model was calibrated to experiment by adjusting the width of the electrodes until the voltage values of each measurement electrode matches the measured value from each container.

Figure 4 shows the measured voltage values of each measurement electrode for both containers (1 and 2). The Figure then gives the final value for each electrode in the computational model after adjusting the width of each electrode. The calibrated width of each electrode, adjusted from the starting value of 2.46 cm (the value is in centimeters instead of inches since those are the units used in the finite element method computational model) are as follows: 2.50 cm (left top), 2.38 cm (left bottom), 2.53 cm (right top), and 2.41 cm (right bottom).

It is observable that the differences in voltage between measured values and the computational model are caused by more then just the width of the electrode. For example, the voltage value will vary if the position of the tape is slightly misaligned or if the tape is not completely uniform in width. The model purposely just calibrates for width because any real system is going to have non-ideal components and noise that will effect the results. By just calibrating for width, the fundamental component of the PCI algorithm of starting with a baseline image and measured parameters, is demonstrated in an actual experiment.

V. EXPERIMENT RESULTS

Once the computational model is calibrated to the experimental results without any cut-out, a cookie cutter is used to remove a circular portion of the gel all the way to the bottom of the container. The circle has a diameter of 4.7 cm with the edges 2.54 cm from the container sides as shown in Figure 5. In order to show a circular hole in the opposite corner the container is rotated 180 degrees resulting in a flip of the positive and negative leads of the function generator.

Figures 6 and 7 show the voltage values of the experimental results compared to the computational model for the two containers. Since the resistance of the function generator is on the same order as the resistance of the gelatin mixture, making a circular hole in the mixture resulted in a change in the peak to peak voltage of the 500 kHz sine wave. The first value (11.9 Volts) refers to the first plastic container and the second (11.8 Volts) refers to the second plastic container.

The maximum variation between the experimental voltage readings and the computational models predicted voltage values in Figures 6 and 7 is 0.3 volts. Considering that the peak to peak voltage readings on the oscilloscope hooked directly from the function generator would fluctuate by 0.2 volts the results are very favorable. Figures 6 and 7 demonstrate that the approximation of Maxwell's equations are appropriate

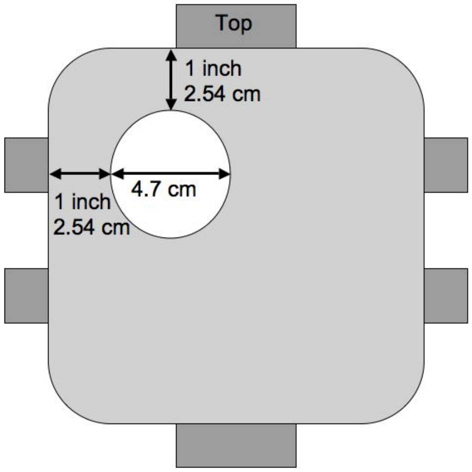

Fig. 5. Location of the circular hole in the gelatin mixture

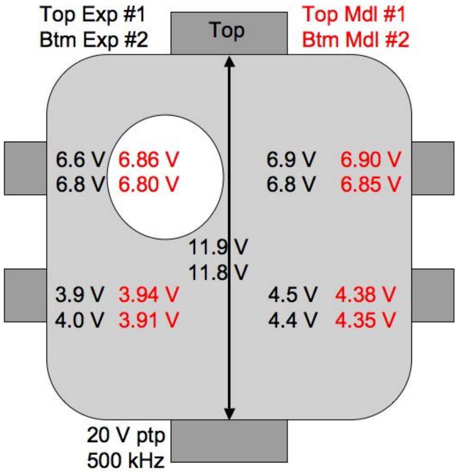

Fig. 6. Voltage comparison with circular cut-out in position A

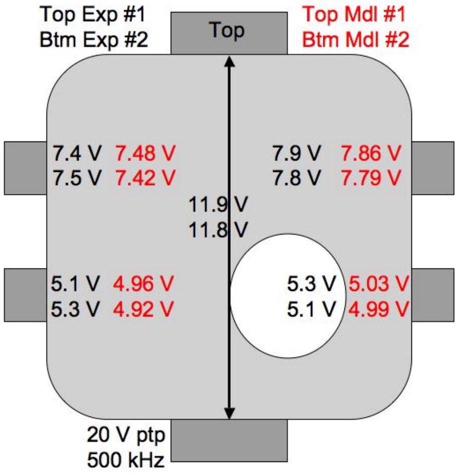

Fig. 7. Voltage comparison with circular cut-out in position B

for this model and that the calibration technique worked well despite any limited noise in the system.

A. PCI Algorithm Results

To demonstrate the PCI algorithm the experimentally determined voltages are used for the measured parameters in the PCI computational model to predict the location of the circular cut-out. The code randomly picks a location for the circular cut-out and then uses a swarm optimization routine[3] to locate the position of the cut out with the lowest error (fitness) compared to the experimentally determined voltages. The swarm optimization routine contained 20 elements and iterated through 20 steps.

Figure 8 shows the predicted location of the center of the circle for both plastic containers. The oblong shape of the circles is caused by the nonuniform divisions in the x-axis compared to the y-axis. The two points closest to the center of the graph (0,0) are from the voltage values taken from container 1, the two points farthest from the center of the graph represent the voltage values taken from container 2. Although there is a discrepancy in the predicted location of the circular cut-out, the accuracy would be sufficient for many applications.

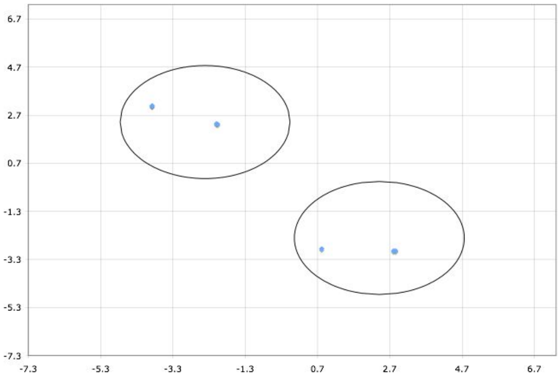

Fig. 8. Predicted center location of the circular cut-out compared to the actual location for both containers

To better understand the reason for the discrepancy in predicting the location of the circular cut-out the PCI algorithm was run using 0.1 and 0.2 volt variations. These voltage values are chosen due to induced noise in the system from the function generator of up to 0.2 volts. Figure 9 shows the variation in the center of the circular cut-out that results from the 0.1 to 0.2 voltage change in each electrodes (only 1 electrode is varied at a time). The four electrodes are labeled Voltage Left Top (VLT), Voltage Left Bottom (VLB), Voltage Right Top (VRT), and Voltage Right Bottom (VRB). The default voltages or the voltage values that gives the ideal center of the circle (-2.41, 2.41) for the four electrodes is given as follows: 6.8556 (VLT), 3.9442 (VLB), 6.9064 (VRT), and 4.3836 (VRB).

It is of interest to note that the variations in the predicted center of circular hole are much larger in the x dimension then they are in the y dimension. This discrepancy results from the applied sinusoidal current being (perpendicular to the x-axis) thus giving a larger voltage variation in the y-axis then in the x-axis. Thus, one of several ways to further improve the results would be to move the applied sine wave by 90 degrees and take a second set of measurements. In general, the PCI algorithm would greatly benefit from multiple data samples, including different types of sensors, applied at different locations.

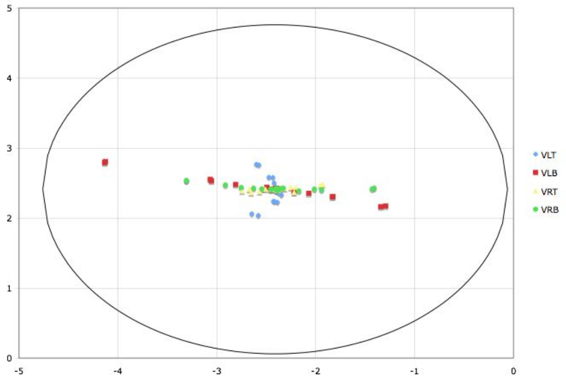

Fig. 9. Variation in predicted center of the circular cut-out for 0.1 and 0.2 volt variations

VI. CONCLUSION

The purpose of this experiment was to validate the PCI algorithm and computational model. The validation experiment highlighted the key components of the PCI algorithm. To be effective the PCI algorithm needs a baseline image, measured parameters, and a computational model with an optimization routine. The baseline image was the homogeneous gelatin mixture which was visually imaged and a knowledge of the size of the circular cut-out, thus the only unknown was the cut-out's location. The experiment successfully showed the approximate location of the cut-out using only the baseline image (the gelatin with no circular cut-out), the applied voltage, the Particle Swarm Optimization routine, and a Finite Element Method model.

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