Opportunity

As a novel subsurface detection method, microwave-induced thermoacoustics (TA) imaging combines the advantages of high contrast of microwave image and high resolution of ultrasound imaging. However, state of the art TA hardware requires the receiving transducer to scan in a linear or rotational fashion in order to be able to collect all needed data to produce the TA image. This process is slow, and adds extra complexity to the system. In order to address this, compressive sensing (CS) methodology can be applied, which has the potential to construct a good image with limited measurements while the signal is sparse. Furthermore, in order to reduce the mutual information shared by different measurements, a holey cavity structure can be applied. In this work, TA imaging theory is introduced and holey cavity structure is studied. The image results reveal the effectiveness of the applications of CS and holey cavity to TA imaging.

Background

TA wave is a result of microwave-induced effect. While exposed to microwave, thermal expansion will appear as the temperature of object rises. Thus, a pressure disturbance is generated at the source and propagates outwards. In most experiments, a pulse signal of microwave will be applied, and the resolution of image is directly related to pulse period. The TA propagation equation can be described as:

\[ \frac{\partial^2 r}{\partial t^2} - \frac{1}{c^2} \frac{\partial^2 r}{\partial x^2} = \frac{\beta}{c_0} \frac{\partial q(r,t)}{\partial t} \]

As shown in Fig. 1, the TA image in Fig. 1a shows better contrast performance than ultrasound image in Fig 1b, and better resolution performance than microwave image in Fig 1c.

The imaging problem can be described by the following equation:

\[ Ax = b \]

where \( A \in \mathbb{C}^{m \times n} \) is the sensing matrix, \( x \in \mathbb{C}^n \) is the unknown vector that stores the contrast variable in the imaging domain, and \( b \in \mathbb{C}^m \) is the vector of measurements, where \( N_b \) is the number of measurements and \( N_x \) is the number of pixels in the imaging domain. According to CS theory, a sparse signal can be recovered with a reduced number of measurements if (1) the sensing matrix of receiver satisfies the Restricted-Isometry-Property (RIP) condition, and (2) the non-zero elements are much fewer than the total number of elements in the imaging domain. Furthermore, in order to enhance the performance of CS in TA, the mutual information shared by different measurements can be reduced by the application of a holey cavity structure. Thus, the parameters of the holey cavity need to be studied to offer the best image.

Approach

Model

A 2D simulation model is established to study the effect of the holey cavity parameters. The complete model is shown in Fig. 2a, and the detailed geometry parameters of the holey cavity are shown in Fig. 2b.

Simulation Parameter

As shown in Fig. 2b, there are many parameters that may affect the performance of the holey cavity. Some of these should be determined considering the geometry limitation of real application, such as the width \( W \) and height \( H \), while other parameters are the interest of optimization. The simulation results of the following parameters are shown in this work due to size limitation.

1) Receiver Location (\( r_f \)): the vertical location of receiver can be altered.
2) Ratio (\( \text{ratio} = \frac{N_b}{N_x} \)): defines the percentage of cavity get blocked.
3) Block Number (\( N_{blk} \)): \( N_{blk} \) defines the number of blocks in cavity.

Results

Receiver Location

Three receivers are used with \( r_f = 15 \text{ mm} \), and \( r_f = 1 \text{ mm} \, 3 \text{ mm} \), \( 5 \text{ mm} \). The image results are shown in Fig. 3. The best image is given in Fig. 3a with \( r_f = 1 \text{ mm} \).

Fig. 3. Image with cavity: (a) \( r_f = 1 \text{ mm} \), (b) \( r_f = 3 \text{ mm} \), (c) \( r_f = 5 \text{ mm} \); image without cavity: (d) \( r_f = 1 \text{ mm} \). (e)

Ratio Study

In Fig. 4a - Fig. 4c, images obtained with ratio increase from 0.1 to 0.5 are shown. As observed, the targets can be detected in Fig. 4b while in Fig. 4c, only one target can be detected. In Fig. 4d - Fig. 4e, a smaller step is taken from ratio \( = 0.12 \) to ratio \( = 0.28 \). It is shown in Fig. 4e that ratio \( = 0.2 \) is the maximum ratio to detect all the targets.

Fig. 4. Image with (a) ratio=0.1, (b) ratio=0.3, (c) ratio=0.5, (d) ratio=0.16, (e) ratio=0.2, (f) ratio=0.24

Block Number Study

In this simulation, the block width \( b \) is set to be constant as \( b = 0.7 \text{ mm} \), which corresponds to ratio \( = 0.2 \), and \( N_{blk} \) is swept from 15 to 30. As shown in Fig. 5, the best image can be found in \( N_{blk} = 20 \) in Fig. 5b.

Fig. 5 image obtained with (a) \( N_{blk} = 15 \), (b) \( N_{blk} = 20 \), (c) \( N_{blk} = 25 \), (d) \( N_{blk} = 30 \)

Conclusion

According to the simulation, the parameters for the best performance of holey cavity are given as \( r_f = 1 \text{ mm} \, b = 0.7 \text{ mm} \, N_{blk} = 20 \). Admittedly, these optimization parameters may change for different configurations, in the presence of limited measurements, the application of the holey cavity can enhance the image quality after the optimization of these parameters.

On-going Work

As the imaging geometry becomes more complicated, such as the porous media shown in Fig. 6a, the implementation of the holey cavity is more significant because of the difficulty of adding extra transducers. For a proof-of-concept experiment, 6 targets are imaged with 9 transducers, as shown in Fig. 6. At the presence of the holey cavity, the image in Fig. 6c has more contrast than that of Fig. 6b, with the same number of transducers.

Fig. 6 (a) porous media (4), 6 targets image (b) without cavity, (c) with cavity

Impact

Application of Holey Cavity in Compressive Sensing for Thermoacoustics Imaging

Chang Liu, Ashkan Ghanbarzadeh Dagheyen, Juan Heredia Juesas, Ali Molaei, and Jose Martinez

Reference

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