3J3-3

Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 395-396
3-5 December, 2014

Real-time feedback control for HIFU system using localized motion imaging

局所振動画像診断法を用いた HIFU 照射のリアルタイムフィードバック制御

Ryusuke Sugiyama[1‡], Kengo Kanazawa[1], Mika Seki[1], Takashi Azuma[1], Akira Sasaki[1], Hideki Takeuchi[1], Keisuke Fujiwara[2], Kazunori Itani[2], Satoshi Tamano[2], Kiyoshi Yoshinaka[3], Shu Takagi[1] and Yoichiro Matsumoto[1] ([1]The Univ. of Tokyo; [2]Hitachi Aloka Medical; [3]Advanced Industrial Science and Technology)

杉山隆介 [1‡]，金沢憲吾 [1]，関美佳 [1]，東隆 [1]，佐々木明 [1]，竹内秀樹 [1]，藤原圭祐 [2]，射谷和徳 [2]，玉野聡 [2]，葭仲潔 [3]，高木周 [1]，松本洋一郎 [1]([1] 東大, [2] 日立アロカ, [3] 産総研)

1. Introduction

Recently, High Intensity Focused Ultrasound (HIFU) has been interested as a minimally invasive modality for cancerous tumors. In this modality, the high energy acoustic beam can create irreversible thermal coagulation at the focus of the trasducer. The HIFU can be confined to the focal region without inducing irreversible thermal damage to the surrounding normal tissue. However, living tissues are acoustic inhomogeneity; therefore, it is neccesary to develop an accurate monitoring system for control of thermal dose.

Ultrasound (US) imaging has been studied as a non-invasive HIFU monitoring modality, because it can provide portability, low cost and spatiotemporal resolution. However, the longitudinal sound speed that is one of an acoustic property changes only a few percent before and after thermal coagulation. Hence, it is difficult to detect the coagulation area from a B-mode image. In contrast, the stiffness of living tissue change drastically. In a typical experiment with liver tissue, the shear modulus after coagulation was approximately 10 times larger than that before coagulation[1]. US coagulation imaging modalities for monitoring based on change of tissue mechanical properies have been reported.

In this paper, our objective the development of a real-time monitoring and feedback system using LMI to control a coagulation size.

2. Methods

2.1 Localized Motion Imaging

Localized Motion Imaging (LMI) is one of the techniques to detect a change of tissue stiffness caused by its thermal coagulation for HIFU treatment[2]. In this method, acoustic radiation force generated by HIFU is used as a mechanical input to deform tissue at the focus, and the tissue deformation is a few ten μm. The acoustic radiation force is modulated by changing the amplitude of US intensity. The size of local vibrated area can be controlled by amplitude modulation (AM) frequency. The tissue deformation is measured by pulse-echo method using an imageing probe placed at the center of the HIFU transducer. After coagulation, the tissue stiffness changes are detected as changes of tissue deformation. The coagulation area is estimated by the decrease ratio of before to after tissue deformation amount.

2.2 Experiment

Experimental setup and our prototype feedback control system using LMI are shown in **Fig. 1**. 16-frames RF data obtained by an ultrasound scanner were acquired within 0.05 s in every 1 s. The computation time for data processing including cross-correlation was within 0.9 s. The control of HIFU exposure time was based on the result of LMI. The target procine liver tissue was embedded in polyacrylamide gel. In this experiment, AM frequencies was 168 Hz. HIFU frequency and intensity were 2.2 MHz, 2.0 kW/cm^2, respectively. The beam propagation distance L shown in **Fig. 2** are 10, 15, 20, 25, 30 mm. The experiments were conducted as follows:

1. HIFU ablation for 30 s without real-time monitoring and feedback control
2. HIFU ablation with real-time monitoring and feedback control until a coagulation length was more than10 mm

In both cases, the coagulation area were removed with incision of the target livers after HIFU ablation, and coagulation lengths were measured with a scale.

3. Results

Real-time LMI images are shown in Fig. 3. Tissue displacement is shown in Fig. 3(*a*). Fig. 3(*b*) shows the decrease ratio of tissue displacement that obtained by normalization using initial tissue displacement.

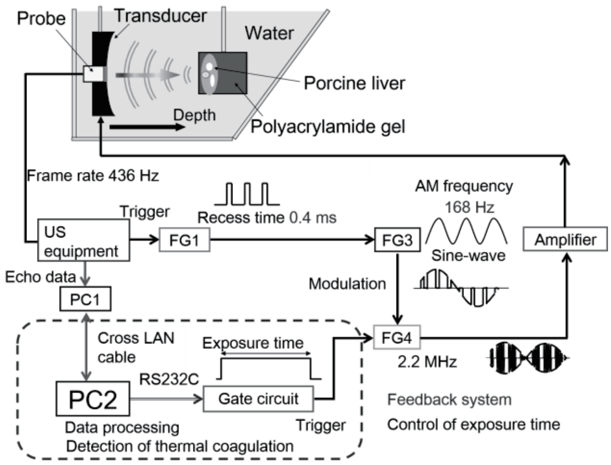

Fig. 1 Experimental setup and prototype system

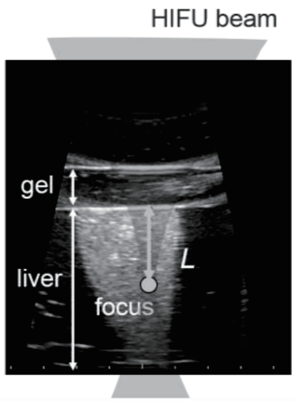

Fig. 2 A B-mode image of liver tissue

The tissue displacement at focus decreases significantly. The expansion of coagulated area in the time axis during HIFU ablation is also observed in this figure.

The results of the coagulation lengths after ablation without and with feedback control based on real-time monitoring are shown in Fig. 4. The circles and asterisks in this figure indicate the results without and with feedback, respectively. The dot-line indicates the targeted coagulation length.

When the HIFU ablation time was constant, the coagulation lengths depended on the beam propagation distance. In contrast, when the HIFU ablation time was controlled by our system, the coagulation lengths were close to 10 mm. The typical size error for the long beam propagation distance (L = 30 mm) were reduced to 12.5 % from 35 %. Experiments to increase the number of samples will be conducted by the USE meeting and these results will be discussed.

4. Conclusion

A prototype feedback control system based on real-time LMI monitoring has been constructed, and HIFU ablation experiments were conducted using this system. By the use of this system, coagulation lengths were close to a targeted length compared to the results without feedback control. The typical error was reduced to 12.5 % from 35 %.

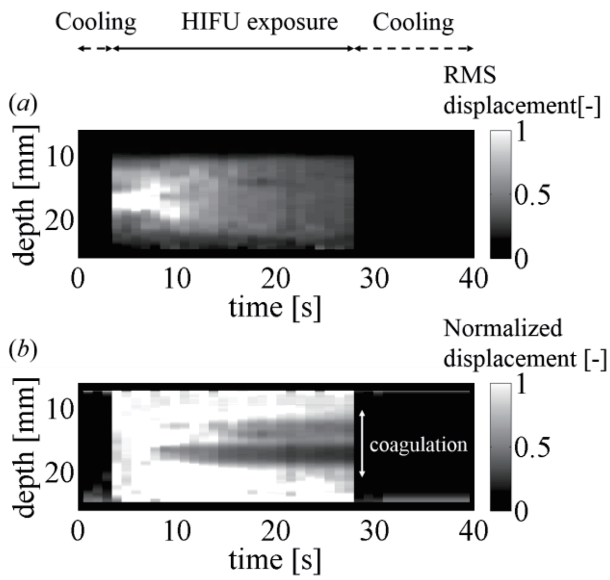

Fig. 3 (a) LMI displacement map and (b) Normalized displacement map

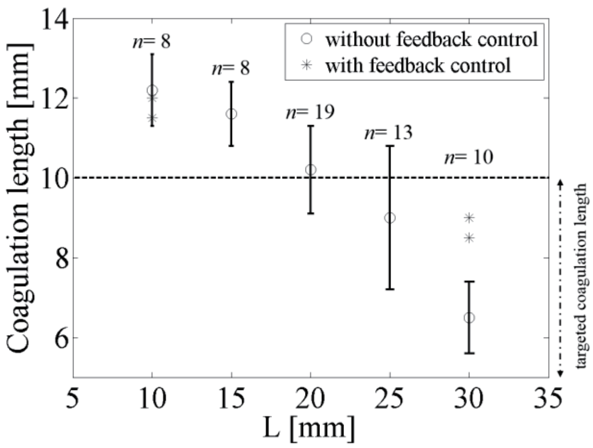

Fig. 4 Coagulation lengths without and with feedback control

Acknowledgment

This work was partially supported by Creation of Innovation Centers for Advanced Interdisciplinary Research Areas Program of MEXT, Japan.

References

1. M. Fink et al., Phys. Med. Biol., 55 (2010), pp. 1701-1708.
2. E. Konofagou et al., Ultrasonics Symp. 2002 IEEE, pp. 1895-1898.