Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

Ultrasound Image Analysis for Renal Stone Tracking During Extracorporeal Shock Wave Lithotripsy

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Abstract— **Although extracorporeal shock wave lithotripsy (ESWL) is the standard procedure for treating renal stones, little work has been done on ways to minimize the side effects and on treatment optimization. A system that uses ultrasound imaging for real time renal stone monitoring is presented here and some aspects of the image analysis module are described. The improved system has proved to be more robust than the unmodified system. With such a system, the injury on healthy tissues is reduced while the treatment time is shortened.**

I. INTRODUCTION

Extracorporeal shock wave lithotripsy can disintegrate renal stones to small fragments so that they can be spontaneously passed out. This is done with focused shock waves that in simple terms are acoustic waves of high rising time and short duration. In order for the shock wave to have some effect on the stone, the stone has to be in the focus area of the shock waves. As the kidneys are located in the upper abdomen they do not maintain a still position but rather follow a movement induced by the movement of the diaphragm due to breathing. The breathing pattern differs among individuals and there is also variability during a lithotripsy treatmend . In addition, movements of the patient due to discomfort add an overall unpredictable offset on the stone position as relates to the shock waves focal area that in the traditional lithotripters is fixed during treatment.

Previous research by our group [1], [2] and others [3], [4] have shown that repositioning the focal area in a way to track the stone position can improve significantly the outcome of the treatment. In the following sections the main principles of the image analysis module in a real time renal stone tracking system are presented.

II. MATERIALS AND METHODS

A. *The lithotripter system*

The lithotripter used for this system is a modified electrohydraulic Litemed 9200 lithotripter (Litemed, Taipei, Taiwan) combined with a 3.5MHz ultrasound imaging system (Hitachi, Tokyo, Japan) and a PC system that performs the image analysis tasks. The ultrasound probe was fixed so that system's imaging plane passes through the focusing area of the shock wave generator. The lithotripter was modified adding servomotors that can shift the shock wave generator and the ultrasound probe together according to the stone position as estimated by the image analysis module. The system outline is shown in Fig. 1. The PC system contains an image grabber that digitizes the analog video signal from the ultrasound system and provides the images for analysis.

B. *The image analysis module*

A typical image of a renal stone is shown in Fig. 2(a) and the major areas in the image are drawn as in Fig. 2(b). The stone appears brighter than other tissues nearby. Nevertheless, it is not the only bright area in the image. Variations on the stone's shape, size, and texture are great between patients making the stone tracking more complex. In the past [4], correlation methods have been used, which usually require

Manuscript received April 2, 2006.

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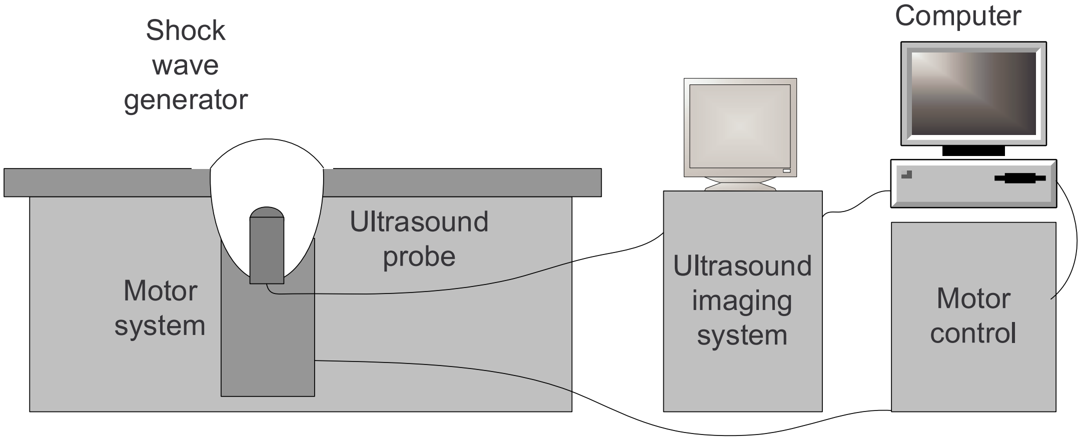
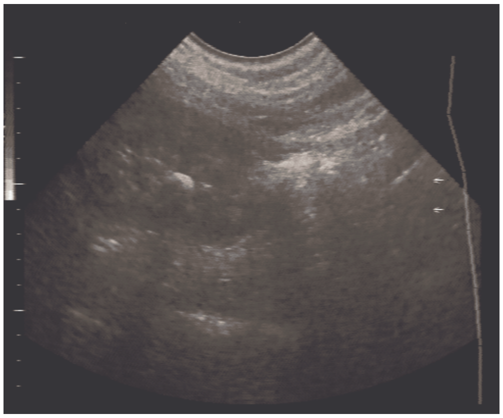


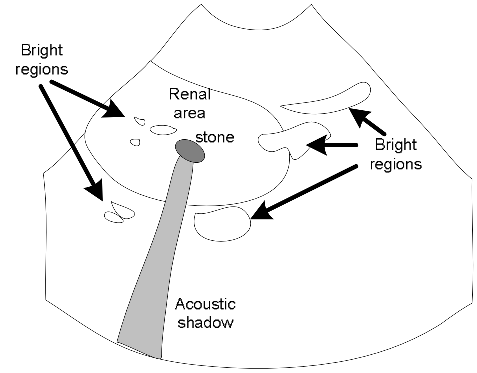
Fig. 1 Outline of the tracking system components.

computation time and do not incorporate any problem knowledge. That system was reported to loose tracking which is a major issue on an automated real time system.

The system presented here is based on the extraction of simple image features which can be followed in a sequence of images. Additionally, the positions at which the stone appears during a short period of system training can give hints to the system on the probable future stone location. The combination of the image features provides a stable and reliable tracking system.

The system can be initialized by clicking the mouse over the stone. This action will set a region of interest (ROI) around the stone. In previous versions of the tracking system ([1]and [2]), the image part within the ROI was used to estimate a global brightness threshold for the ROI and estimated for each image frame. Values over the threshold were considered as possible stone pixels. This method is efficient only when the stone area pixels are the brightest in the ROI and/or the image is uniform. In ultrasound imaging this is seldom achieved. If other tissues are presented with high brightness values then the tracking may deviate to track these tissues. The improved method presented here is not using a global threshold but rather brightness peek detection. The peeks areas are extended to a predefined brightness level range to form larger areas. Small isolated areas of just few


(a)



(b)

Fig. 2 A typical renal stone image is as shown in (a). The outline in (b) shows the areas of the image that correspond to the kidney, the stone its acoustic shadow area and some other tissue that appear as bright regions

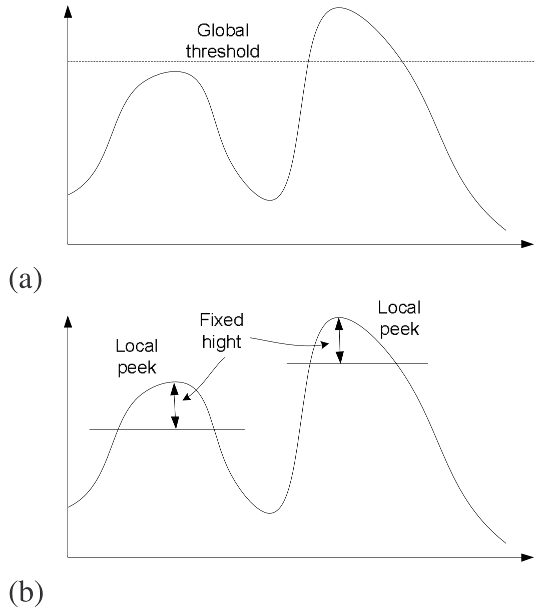


Fig. 3 Global threshold methods cannot detect bright areas at lower brightness (a), where local peek detection can be more efficient (b).

pixels are excluded. The resulted regions are then considered as possible stone locations. The two methods are presented graphically in Fig. 3.

The next image feature incorporated is the stone's acoustic shadow. As renal stones do not permit ultrasound waves to penetrate them, a darker sector area is present bellow the stone. This feature also cannot be regarded in the software as a main feature since there is great variation between different patients or during any single treatment. As a stone gets fragmented, its appearance changes and the stone fragments may allow a portion of the imaging ultrasound waves to penetrate, therefore reducing the chance for a clear acoustic shadow. During tracking, the peeks positions detected as described above are used as seeds for shadow detection. A figure of merit is calculated in the direction that the shadow should appear. This figure of merit is a combination of image features such as the standard deviation of the brightness values in the shadow region, the maximum brightness value within the stone region as well as the brightness energy on the left and on the right of the shadow area.

In the next step, the possible stone regions detected in the previous frame and in the current frame are matched. A figure of merit is calculated for a preset range of possible x-y translations of the ROI. This figure gives merit to the overlapping between the detected regions in the previous and current frames. At each translation, the calculated figure of merit is associated with the region in the current frame closest to the position of the stone in the previous frame plus the translation.

Furthermore extra figure of merit is assigned to the regions in the current frame according to their proximity to the prerecorded stone path in the image.

The above described figures of merit are combined to one total figure of merit according to the operator's settings. The region that corresponds to the highest total figure of merit is set to be the new stone location. This procedure is repeated for every acquired image frame in real time. The image frame acquisition rate is preset to fifteen frames per seconds in order to match the frame rate of the ultrasound system used here.

III. RESULTS

The method presented here was tested with prerecorded videos of renal stones during treatments with traditional lithotripters. The new method was more robust with the peek detection method. Resetting the actual position of the stone was rare and only in extraordinary cases where the patient had moved away from the ultrasound probe, the probe was under repositioning, or the patient had moved in a new position that there was no stone present in the image. In such cases, the system operator would be already aware of the possible loose of tracking and pause the stone tracking.

In Fig. 4 two images of a stone during tracking are shown. The new stone position is shown with a cross mark, the location of high matching figure with a small square and the strongest shadow location and direction is shown with a line. In Fig. 4(a) the image

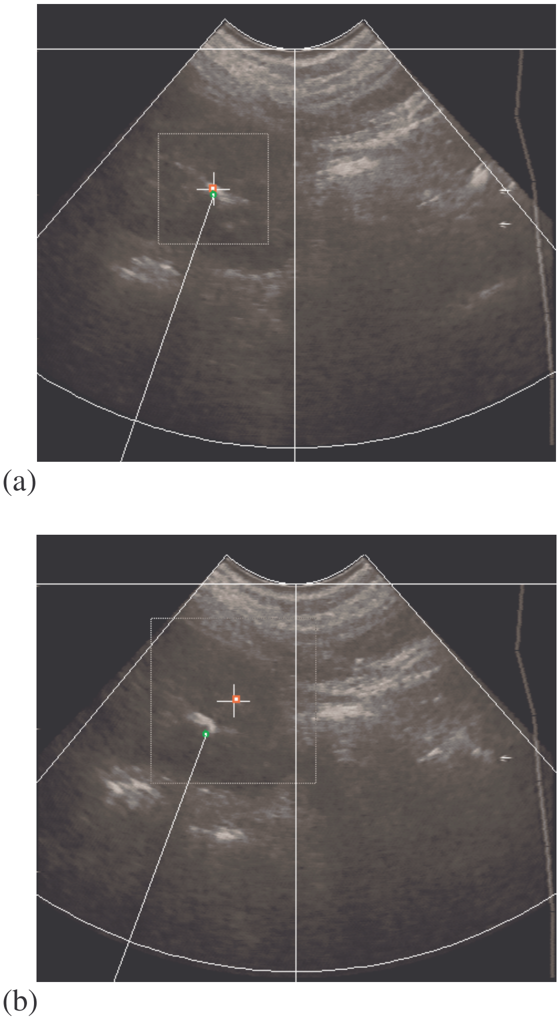


Fig. 4 In (a) there is good correspondence of image features with the actual stone location. The cross denotes the position of the stone in the frame. The square shows the frame matching strongest result location and the circle with the line shows the location of the strongest shadow. In (b) the user has selected another bright region. In this case the system can recover automatically and follow the actual stone.

features show good correspondence with the actual stone. In Fig. 4(b) the user has deliberately selected a nearby bright small region. The system can automatically recover and follow the actual stone because tracking the actual stone produces better figures of merit.

In Fig. 5 previous positions of the stone are shown collectively as recorded within a short period of time.

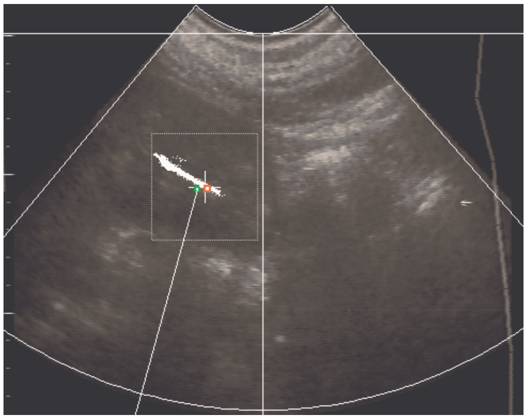


Fig. 5 Recording of previous stone positions. The white region represents pixels that have been detected as stone positions in previous images.

IV. CONCLUSIONS

The main principles used in an ultrasound image analysis module for renal stone tracking were presented. This module comprises of simple image features that can be obtained in real time. The image features relate to knowledge on the image domain. The system presented here has proven in practice to be quite robust and can reduce the shock waves needed for a stone treatment. This results in less tissue injuries as well as reduced treatment time. The case where there is room for improvement is when the stone is moved outside the imaging plane. In this case it is still possible for the system to follow other bright structures if not supervised.

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