AN APPLICATION OF THE OPTICAL COMPUTER: INVESTIGATION OF A HIGH-SPEED DYNAMICS OF A BUBBLE

NJË ZBATIM I KOMPJUTERIT OPTIK: HULUMTIMI I DINAMIKËS SHUMË TË SHPEJTË TË NJË MËSHIKËZE

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Abstract

An optical correlator is introduced for implementation of mathematical morphology (MM). This optical computer is applied to study dynamics of a bubble formed during the laser lithotripsy. The high-speed phenomena and the collapsing mechanism are investigated in order to determine the collapsing point of the bubble. By subtracting the eroded image from its original or original image from the dilated version, the edge detection and the collapsing point of a bubble is determined. The structuring element (SE) used to perform the MM is selected according to the structure of the bubble image. The selected SE is akin to the physical pressure of the fluid where the bubble is formed and collapsed.

Keywords: Laser lithotripsy, Gallbladder stone, Bubble, Mathematical Morphology

Përmbledhje

Formimi i një mëshikëze në brendësi të një fluidi pas shkrepjes së një impulsi ultra të shpejtë nga lazeri me Ho:YAG dhe plasja e saj janë studiuar me anë të përpunimit optik të imazheve. Këtu propozojmë një teknikë të bazuar në përpunimin optik të të dhënave për të kryer disa operacione matricore të cilat përbëjnë morfologjinë matematikore (MM). Dy operacionet bazë të MM dhe kombinimet e tyre janë zbatuar për të studiuar dinamikën ultra të shpejtë të formimit të mëshikëzës. Imazhet e saj janë kapur duke e ndriçuar atë me dritë nga lazeri me Nd:ngjyrosës

(Nd:Dye), me kohëzgjatje prej vetëm 7 nanosekondash. Teknika që propozojmë këtu është treguar efikase për përpunimin e imazheve në intervale ultra të shkurta kohore, me qëllim të parashikimit të pozitës apo pikës së plasjes së mëshikëzës. Përpunimi optik është realizuar me anë të një korelatori i cili bën dy transformime dydimensionale Furie. Në planin e korelacionit është bërë prerja apo pragëzimi optik (thresholding) duke realizuar operacionet e kërkuara të morfologjisë matematikore.

Fjalët kyçe: kompjuteri optik, dinamika ultra e shpejtë, plasja e mëshikëzës, lazeri me Ho:YAG, korelatori optik, morfologjia matematikore, transformimet dydimensionale Furie

1. Introduction

The phenomena and dynamics in the laser lithotripsy process are not fully understood [1-8]. These phenomena are akin to laser lithotiropsy which is promising approach for removal of the stones inside of the gallbladder or kidney of the human body.

Most of our present understanding of this dynamics has come from high-speed photography, shadowgraphy and spectroscopic studies [4].

It is shown in the literature that in the use of laser power, cavitations bubbles are understood to be the driving force for cutting a tissue and destroying a stone [7-9].

As described above such bubbles result from an explosive evaporation of water due to dielectric breakdown [10-18] or radiation absorption in water [18-19] or tissue [20-23].

Formation of the bubble and destruction mechanism of the stone has been addressed elsewhere [24, 26]. Here we study the dynamics of a bubble or its collapsing point using mathematical morphology (MM). This could be used for practical application of laser lithotripsy [27-28]. Before we apply it, we describe this mathematical concept briefly.

Mathematical morphology consists of a set of transformations that transform a set into another set. The goal of these transformations is to find specific geometrical structure in the original one. These transformations are carried out via the use of another smaller set, known as the structuring element (SE), which contains the desired geometrical structure. The transformed set contains the information about that structure. Various interactions of the original set with the structuring element form the basis of all morphological operators. Mathematical Morphology, developed by Serra [29], is basically a set theory that uses set transformations for image analysis [30]. It extracts the impact of particular shape on images via concept of (SE). The SE encodes the primitive shape information. In a discrete approach, the shape is described as a set of vectors referenced to a particular point, the center, which does not necessarily belong to SE. During morphological transformation, the center scans the whole image and matching shape information is used to define the transformation. The transformed image is thus a function of SE distribution on the original image.

The two most fundamental transforms of mathematical morphology are erosion and dilation. Using their combinations two more operations known as opening and closing can be performed. Let *P(E)* be the set of all subsets $X \in E$. Consider an arbitrary space (or set *E*), with each point *X* of space *E*. Another spatially varying set *B(X)* called the SE is associated with the above set. The set $X \in P(E)$ can be modified based on set transformation of *X* by *E*. Let B_x denote the translate of *B* by the vector *x*.

Erosion: {*X:* B_x ⊂}inters x of translate B_x included in *X*.

The eroded Set of *X* is the locus of centers x of translate B_x included in the set *X*. This transformation looks like the classical Minkowski subtraction $X \Theta B$ of set *X* by *B*;

$$X \Theta B = \bigcap_{b \in B} X_b \quad (1)$$

Dilation is another operation which combines two sets using vector addition of the elements. Dilation is related to Minkowski addition of Integral Geometry.

If *A* and *B* are sets in *N*-dimensional space (E^N) with elements of *a* and *b* respectively, $a = (a1, a2\ldots, a_N)$ and $b = (b1, b2\ldots, b_N)$, being *N*-tuples of element coordinates, then dilation *A* by *B* is set of all possible vector sums of pair of elements coming from *A* and one coming from *B*.

Dilation is a dual transform of erosion and can be expressed as:

$$X \oplus B = (X \Theta B)^C \quad (2)$$

where ⊕ denotes dilation, and *C* denotes complement.

Let *A* be a subset of E^N and $x \in E^N$. Translation of *A* by *x* is denoted by $(A)_x$ and is defined by

$$(A)_x = \{c \in E^N \mid c = a + x \text{ for some } A\}$$

The dilation $X \oplus B$ can be computed as the union of translations of *A* by the elements of *B*

$$X \oplus B = \bigcup_{b \in B} (A)_b \quad (3)$$

The next two important operators: erosion followed by dilation and dilation followed by erosion constitute the opening and closing operation, respectively.

2. The optical implementation of mathematical morphology

Now we investigate the bubble and its collapsing mechanism using optically implemented morphology. We have shown that Mathematical Morphology is based on scanning process and set operations. When an input image is color or gray-scale, its decomposition and subsequently hundreds of set operations must be performed in order to complete the morphology operation. Hence a very fast computer and a long-time should be spent for morphology processing of an image. David Casasent and his coworkers proposed an optical implementation of Morphology [31-33] using correlation. The same technique is applied here for morphological investigation of a bubble. The optical setup is shown in Fig.1:

The image of a bubble to be processed is placed in plane P1 and a matched spatial filter (MSF) of the morphological structuring element (SE) is placed in P2. The correlation output at P3 is thresholded high leading to erosion or operation as represented by equation (1). The dilation operation represented in equation (2) is performed by a low thresholding of the output image at plane P3.

Using optically implemented mathematical morphology the edge of the image is obtained. Three different cases are performed. First, the performed edge is placed at the edge of the original image by subtracting the dilated image by the eroded output of the same. Secondly, by subtracting the original image from the dilated image, the obtained edge is greater or outside the original image. And finally the edge can be smaller than the original image when subtraction of the eroded image from the original one is performed.

3. Results of morphology operation: Identification of the collapsing points

In Fig.6.a the binary version of the original image of a spherical bubble is shown. This bubble was experimentally obtained when the tip of the fiber delivering the laser pulse was far away from the stone. This is the case of the so-called free-developing bubble. Erosion was performed on the original image, by using a symmetric structuring element (SE3x3). The result is shown in Fig.2.b and is denoted Ero.O.Im.SE3x3. The next step is dilation operation performed on the original image by using the same structuring element. Result is shown in Fig.2.c and denoted by Dil. O.Im.SE3x3. By subtracting the eroded image (Ero.O.Im) from the original im-

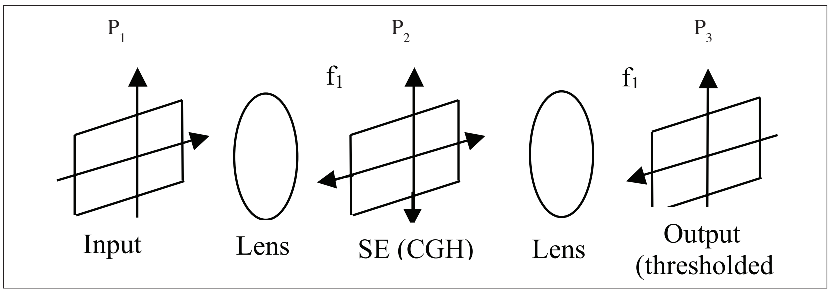

Fig.1 Morphological processor using an optical correlator

age (O.Im) the edge detection is performed and shown in Fig.2.d and denoted by O.Im-Ero.Im. In this case the contour is placed inside the original image.

By subtracting original image from the dilated one the contour of size greater than original image is obtained and shown in Fig. 2. e. This is denoted by Dil.O.Im-O.ImSE3x3.

Fig.2.a O.Im | **Fig. 2.b** Ero.0.Im. SE3x3 | **Fig.2.c** Dil.O.Im.S E3x3 SE3x3

Fig. 2.d O.Im-Ero.Im SE3x3 | **Fig. 2.e** Dil.O.Im-O.Im.SE3x3 SE3x3 | **Fig. 2.f** Dil.O.Im-Ero.O.Im SE3x3 | **Fig. 2.g** Dil (Dil.O.Im-Ero.O.Im) SE3x3

Fig. 2. Morphology, edge and critical point detection

The contour obtained by morphology operation is overlapped with the contour of O.Im by subtracting the eroded image from dilated one. Result denoted by Dil.O.Im-Ero.O.ImSE3x3 is shown in Fig. 2.f. Finally, dilatation is performed one more time on image Dil.O.Im-Ero.O.Im by using SE3x3. The result is shown in Fig. 2 g and is denoted by Dil (Dil.O.Im-Ero.O.Im) SE3x3.

Three different results, shown in Fig. 2a-f, are performed in order to investigate whether the density of the fluid in the region outside, inside and on the space of the contours of the original image is uniformly distributed or not. Results obtained in Figs 2.a-f show that the contours of these three images are of different sizes but are homologous. Figs.2.d-f show that on the top and on the bottom of the contour there are interruptions. These interrupting points indicate the place where the energy of the bubble is released at the end of its life (collapsing moment). The interrupting places on the contour are emphasized clearly when dilation is performed on Dil.O.Im-Ero.O.Im. This image is considered more reliable to study the place of interrupting points or the places where the energy of the bubble is released. Therefore, in the next step only this phase of morphology operation will be used.

4. Detection of the collapsing points of the bubles with different shapes

In the following part of the experiment the collapsing points and their loci in the contour of the bubble is studied. For this only Dil (Dil.O.Im-Ero. O.Im) will be used. Results obtained for different shape of the bubbles or contours in the Figs. 3.a-c are shown. As is mentioned above, the shape of the plasma and the bubble depend on the experimental conditions applied during the action of the laser pulse for destruction of the stone. In the case shown in Fig. 3.a the bubble B1 or its contour is of elliptical shape.

Fig.3.a-B_1 Dil (Dil-Ero) **Fig. 3.b**-B_2 Dil (Dil-Ero) **Fig. 3.c**-B_3 Dil (dil-Ero)

Fig.3. The collapsing points for different contour shapes

Here points indicating the collapsing loci at the bottom and at the top of the contour are shown. The position of the fiber relative to the surface of the stone was different for the cases shown in Fig. 3.b and Fig. 3.c. Therefore, different shapes and loci of the interruption of the contours is obtained. While the collapsing point in case shown in Fig.3.b is on the top of the contour, in case shown in Fig.3.c the locus of the collapsing point of the bubble is at the bottom of the contour. The locus of the points indicating the place where the energy is released has an important role for an efficient destruction of the stone when the laser power is used.

5. Conclusion

The locus of the collapsing points of a bubble is studied by applying optically implemented morphology. It is shown that when the tip of the fiber is far away from the surface of the stone the bubble formed has a spherical shape. In this case position of the collapsing point is hard to be predicted. This is because there are more than one collapsing points. In case when the tip of the fiber is closer to the surface of the stone the shape of the formed bubble is elliptical. In this case there is only one collapsing point. Therefore its position is easier to be predicted. The collapsing point and its position indicate the point where the main amount of energy and a jet responsible for destruction of the stone is released. One would desire that the collapsing point is closer to the surface or attached to the surface of the stone. Otherwise, if the collapsing point and the release of the energy is not directed towards the surface of the stone but towards the gallbladder tissue, the risk of applied laser power will be higher. We have shown that a vertical position of the axis of the fiber to the surface of the stone is the most optimal position for laser-based lithotripsy.

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