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# Estimation of 2D strain in abdominal organs during an impact based on ultrafast ultrasound images: a physical landmark-based approach

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## Résumé

*Dans un contexte de validation de modèles humains en situation d'accident, l'échographie ultrarapide rend possible l'observation du comportement interne d'organes abdominaux, avec toutefois une qualité d'image qui rend difficile l'utilisation de techniques de post-traitement classiques. Cette étude présente une méthode d'estimation de déformations 2D d'organes abdominaux imagés par échographie ultrarapide. Dans cette méthode, des marqueurs sont détectés sur chaque image du film échographique à l'aide d'un logiciel développé initialement pour le suivi automatique de cellules biologiques puis, via des étapes de filtrage, d'interpolation et d'intégration, des champs de déformations sont calculés. Pour l'instant, les prédictions ont été vérifiées (1) en comparant les déplacements estimés à ceux issus d'un suivi expert et (2) en appliquant la méthode à une image déformée numériquement un champ de déformation inhomogène connu. Enfin, dans le but d'évaluer la robustesse de la méthode notamment en présence de bruit échographique, un protocole de validation expérimentale a été développé. Il permet de comparer les déformations prédites par la méthode à l'intérieur d'un échantillon fin à celles mesurées par stéréo-corrélation sur la surface externe. Les essais sont en cours.*

## Abstract

*Within the context of human body models validation for accident configurations, ultrafast ultrasonography makes possible the observation of internal abdominal organs, but with a reduced image quality that makes difficult image post-processing with classical methods. This study describes a new method to estimate 2D strains in organs based on ultrafast images. This method is based on an automatic tracking algorithm initially developed for biological cells combined with filtration, interpolation and integration steps. So far, the predictions were verified (1) by comparing estimated displacements with those derived from manual tracking and (2) by applying the method to an image deformed numerically using a known inhomogeneous strain field. Finally, in order to assess the robustness of the method to ultrasound noise among others, an experimental protocol was developed. It allows comparing strains assessed by the method inside a thin biological sample with those measured by stereo-correlation tools on the external surface. The tests are ongoing.*

**Keywords:** strain, ultrafast, ultrasound, landmark, abdomen

# 1 Introduction

During an automotive accident, the abdomen can be subjected to large deformations leading to internal organ injuries. Although the external response of the abdomen has been studied extensively, internal organ kinematics during an impact is largely unknown. This makes the validation of the internal response of human abdominal models difficult. Typical impacts duration last a few tens of milliseconds and standard imaging tools such as MRI are too slow for such durations. For that purpose, besides X-ray based methods [1], methods based on ultrafast ultrasound imaging have been recently proposed. Two recent experimental studies provided results regarding the internal response of isolated porcine kidneys during an impact [2] as well as the internal kinematics of in-situ organs during an impact [3]. However image processing is currently limited in these studies. Natural targets were tracked semi-automatically because of the poor quality of the images and, in the case of the kidney, uniaxial strains were computed between targets. This is a limitation as the manual selection of targets can lead to an operator bias and the tracking of numerous targets would be time consuming. Moreover through-plane motions may occur and make the natural targets appear and disappear. Many processing methods based on deformable image registration have been developed in particular to study cardiac motion from ultrasound images [4]. Such methods must respect properties of the field computed such as invertibility, topology preservation or diffeomorphicity. For that purpose, the deformation shape can be inspired from a physical model such as a finite element model [5] or derived by interpolation or regression. Most of the time, they are based either on Radial Basis Functions (RBFs) or on free-form deformation (FFD) combined with spatial conditions to force the displacement field to be locally smooth, as well as temporal conditions in order to ensure the temporal continuity [6]. Such methods have not however been applied to ultrafast imaging data. The aim of this study is to develop a method that estimates 2D strains in organs subjected to impact based on ultrafast ultrasound images.

## 2 Methods

### 2.1 Process

This method is based on an automatic tracking algorithm developed for very noisy images using geometric local descriptor matching. Landmarks are first detected on each image by extracting local minima in a Difference of Gaussian (DoG) space. Geometric local descriptors are defined from each landmark and its closest neighbors. Correspondences from an image to another are established first for each descriptor. Then to ensure that correspondences are physically plausible for a descriptor, it is checked if an affine transformation between images can be found using a Random Sample Consensus (RANSAC) process [7].

The remaining landmarks whose kinematic parameters are not compatible with experimental boundary conditions, impact velocity or possible acceleration fields are rejected.

A smooth velocity field is then derived by spline interpolation between subsequent images. Displacement fields are obtained for each pixel by integration along the time axis. Strain fields are finally derived from Green-Lagrange equations.

### 2.2 Validation methodology

The algorithm was already subjected to two validation steps.

- 1) Ultrafast ultrasound images showing the interior of porcine kidneys were processed using the proposed method. The computed displacement field was compared with landmark trajectories derived from expert tracking.

- 2) Synthetic images were generated by applying a known inhomogeneous time-varying strain field. The proposed method was then applied to the stack of synthetic images in order to check its ability to predict the applied strain.

### 3 Results and discussion

For the two validation steps:

1) Vertical displacements computed using the proposed method and points manually tracked in an ultrasound sequence are compared in Figure 1. The points were chosen because they are located on the boundary of anatomic structures (cortex/pelvis). In that case, the displacements predicted by the proposed method were found to be consistent with those obtained by expert tracking within less than 10%.

2) The proposed method predicted the inhomogeneity of the strain field applied to the image stack (Figure 2). It was found that a random deformation field up to 30% applied to an original image can be predicted through the proposed method, although with some artefacts near the edge of the image.

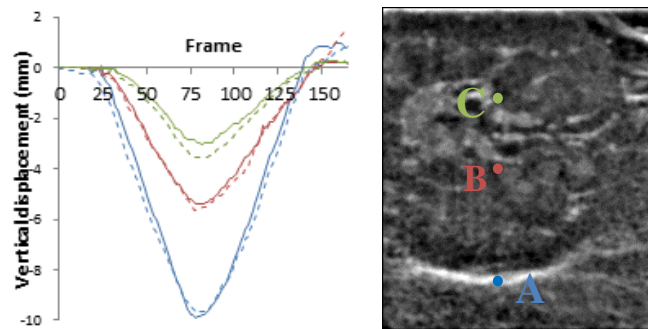


Figure 1: Left: vertical displacement of points A (blue), B (red) and C (green) expertly tracked (solid) and assessed (dotted). Right: positions of the points over an ultrasound image (interior of porcine kidney compressed at 0.3m/s, 2000 images/sec)

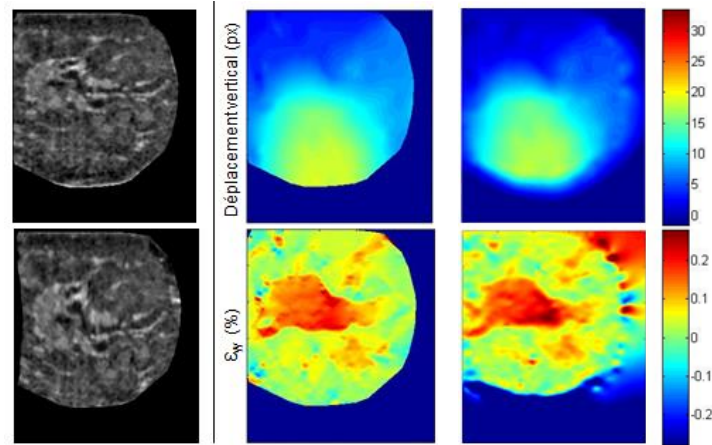


Figure 2: Original (a) and deformed (b) image. Known (c) and assessed (e) vertical displacement field. Known (d) and assessed (f) vertical strain field.

Although these validation steps are necessary, they are not sufficient for example to show the robustness of the algorithm towards the ultrafast ultrasound type noise and limited through-plane motions. An experimental validation method was therefore developed. A random pattern is painted on the two surfaces of a thin sample of bovine muscle. The sample, partially immersed and laying on a transparent plate, is subjected to manual compression along its long axis. Two stereo camera rigs compute the external strains based on the paint patterns (stereo-correlation software, Vic-3D®). Simultaneously, an ultrasound probe is used to image the mid-plane between the external surfaces. The proposed method is then applied to the ultrasound images and predicted strains are compared to those obtained by stereo-correlation. Preliminary experiments have been conducted and the assessment of the proposed method is still ongoing.

## 4. Conclusions

This study describes a method to estimate 2D strains of abdominal organs subjected to an impact based on ultrafast ultrasound images. The method is based on an automatic tracking algorithm combined with additional spatial and temporal conditions. The preliminary steps of numerical validation have shown the interest of the approach, and could already allow expanding upon the current analyses. An experimental validation is ongoing to evaluate the robustness of the method to noise in the ultrafast ultrasound images and to assess its limits in terms of strain amplitude.

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