Image Registration for Quantifying Deformation in Penetrating Ballistic Impacts

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Abstract. Quantifying deformation and strain fields in tissue surrogates during ballistic impact and penetration presents many challenges. Currently, quantitative analysis is difficult due to the limitations of implanting transducers and current video technology. We propose an automatic method based on established medical image registration technologies, and which affords a high level of flexibility. The method was applied to video images of a projectile penetration into ballistic gelatine. The gelatine specimen was also injected with a grid of ink markers to help visually assess the evolution of its deformation around the projectile. The conclusion is that image registration allows for effective estimation of the surrogate response to penetrating impact.

Introduction

High velocity fragments generated by explosive devices are an important cause of injury in conflicts worldwide. Fragmentation of the device's casing is designed to increase lethality and effective range. Better understanding of the interactions between fragments and biological tissues requires methods of quantitatively assessing tissue deformations during penetration; this includes the permanent cavity and the temporary cavity that has been previously identified [1]. Yet experimental methods so far have mainly been qualitative, and based on high-speed video (HSV) technology. Fiducial markers implanted in, or attached to, the specimen may, in principle, provide reference points for quantitative measuring of displacements. However, this is a laborious manual process which can lead to artefacts, depending on the temporal and spatial resolution, and density of marker pattern. Modelling techniques have been used [1] but correlating such models with experiments remains difficult. Digital Image Correlation or Transmission Photoelasticity are also possible approaches to quantitative analysis displacement but their area based methods require a dense speckle pattern or identifiable fringe pattern to calculate the displacement. Measurements using implanted transducers can provide experimental data, but only limited to the single points of data collection. In this work we propose an image registration method that estimates the deformation field from HSV data in the plane of the penetrating impact.

Theory

Image registration is the process of aligning one image to another and can be applied sequentially over a series of consecutive images. In general, "non-rigid" registration involves warping one image (the source) so that all corresponding points in the images are properly aligned to the target image. This warping is achieved using a transformation model, which provides a mapping between the configurations depicted in each image. In this work, a B-spline transformation model is employed [2]. The registration process then involves finding the B-spline knot positions that yield the optimal alignment between the images, as determined by a chosen similarity metric. The overall process is depicted in Fig. 1.

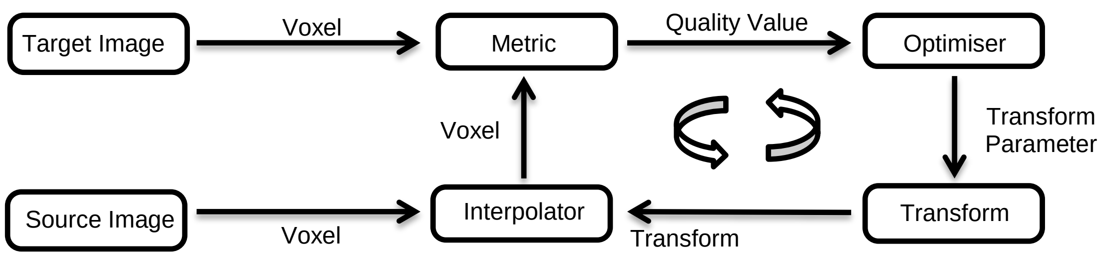

Fig. 1: Graphical representation of the image registration process.

The similarity metric used is pattern intensity $P_{r,\sigma}(s)$ [3], defined as:

$$P_{r,\sigma}(s) = \sum_{i,j} \sum_{d^2 \le r^2} \frac{\sigma^2}{\sigma^2 + \left(I_{dif}(i,j) - I_{dif}(v,w)\right)^2}, \quad (1)$$

where r defines region size, σ is constant used to weight function, I_{dif} is difference image, $d = (i - v)^2 - (j - w)^2$ radius from voxel, i, j coordinates of current voxel and v, w coordinate of voxel being compared to current voxel at radius d. This is a regional voxel method that identifies patterns in defined regions around each voxel in the image. Once the transform grid has been extracted it is used to calculate the displacement $\mathbf{u}(\mathbf{X}, t)$ at position $\mathbf{X}$ and time t by applying the transform function consecutively from the initial image in the sequence [4].

Experiments

Penetration experiments were performed to provide data for the image registration process, with the aim of simulating the impact of a fragment on human tissue, at velocities comparable to those generated by explosive ordinance. The launch velocity was determined from literature and an analytical study. Penetration experiments used an air cannon to fire a 6 mm steel ball bearing vertically upwards into a tissue surrogate target. 10%wt Scientific Ballistic Gelatine, set into blocks, were used as the tissue surrogates. Penetration was observed using a Phantom v210 HSV camera recording at 8501 frames per second. The gelatine blocks were injected with a sparse grid pattern to aid in tracking of deformation in the surrogate. The images were cropped to remove unnecessary components using Phantom Cine Viewer software [5]. Image registration was performed using an open source Matlab toolkit [6]. Using the extracted transformation grid, a cumulative displacement field was then produced.

Results

The image registration proved to be effective in capturing the cavity motion and tracking the penetration of the ball. The displacement patterns (Fig. 2) reflect the border of the cavity and trace the progress of the ball through the surrogate. Similarly, surrogate motion away from the cavity can be observed. Image blur resulted from a combination of lens effects, spatial resolution and temporal resolution, and was minimised by optimising the camera and back lighting arrangement.

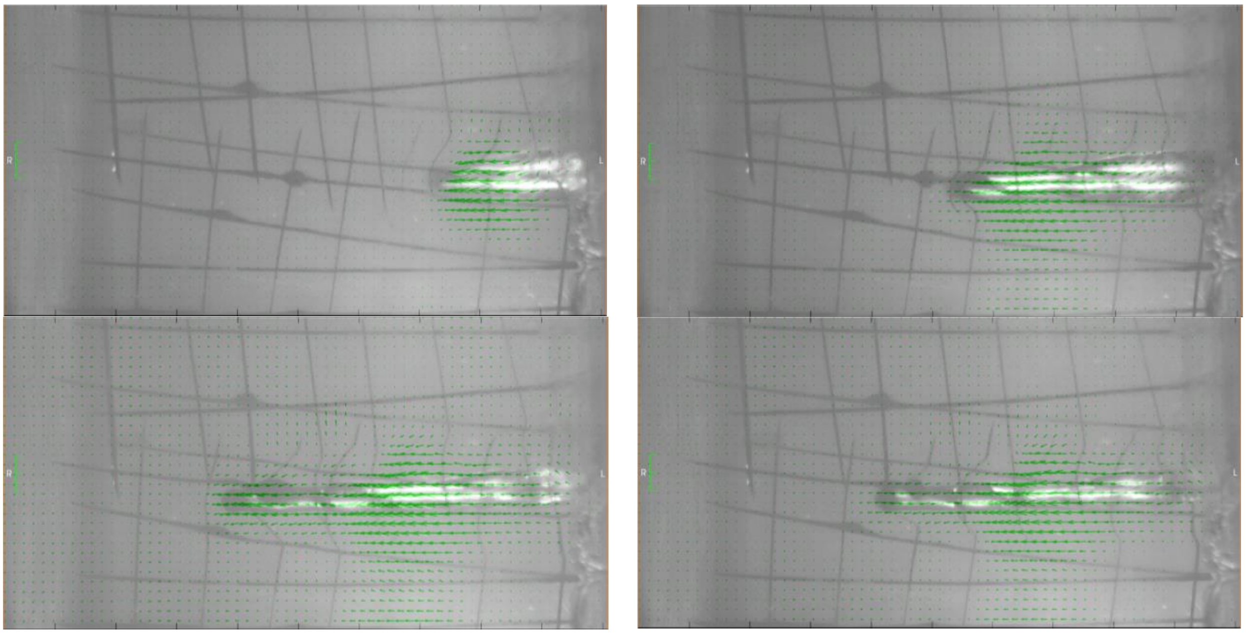

Fig. 2: Registered images overlaid on the displacement field, for a sequence of time points (clock-wise from top left): 0.23×10^{-3} s, 0.82×10^{-3} s, 1.4×10^{-3} s, 2.0×10^{-3} s.

Conclusion

The proposed method offers the possibility of automatically estimating displacement fields in video sequences of projectile penetration events. Future work will focus on derivation of strain and other fields from these results, and their use in investigating projectile-tissue mechanics.

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