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AN IMPROVED REAL-TIME OPTICAL FLOW TRACKING TECHNIQUE FOR MR-GUIDED BEAM THERAPIES IN MOVING ORGANS

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ABSTRACT

This study aims to improve real-time respiratory motion tracking through an algorithm having increased robustness to gray-level intensity variations from other sources than motion. These developments are shown to be potentially beneficial for magnetic resonance-guided (MRg) high intensity focused ultrasound (HIFU) and external beam radiotherapy (EBRT) interventions in the abdomen, where cardiac activity might become problematic for current approaches.

Index Terms— Real-time MR-guidance, optical flow, HIFU, EBRT

1. INTRODUCTION

MRg-HIFU and EBRT, show great potential for the non-invasive treatment of tumors in abdominal organs. Therapy delivery in such areas is, however, hampered by respiratory motion. To overcome this problem, previous studies suggested combining high-frame-rate MR-imaging with a real-time optical flow algorithm such as suggested by Horn&Schunck [1, 2]. However, this approach is intrinsically also sensitive to gray-level intensity variations from other sources than motion, such as in-flow enhancement/pulsations due to the cardiac cycle, which frequently leads to tracking errors. In this work, an improved real-time tracking algorithm with increased robustness versus such effects is proposed and experimentally compared to the original Horn&Schunck method in terms of quality of the motion estimates in the presence of arterial pulsations.

2. MATERIALS AND METHODS

The original Horn&Schunck functional shown in equation (1) relies on a signal intensity conservation term and a regularization term, which imposes a smooth differentiable motion [2].

$$E_{L2L2}(u, v) = \iint_{\Omega} (I_x u + I_y v + I_t)^2 + \alpha^2 (\|\nabla u\|_2^2 + \|\nabla v\|_2^2) dx dy \quad (1)$$

For motion tracking this functional has to be minimized in real-time for each image of the data stream. Problematic are hereby intensity variations due to arterial in-flow artifacts, which frequently violate the intensity conservation and thus lead to mis-registration. As consequence, we propose a modified $L^2 - L^1$ functional (equation (2)), which replaces the quadratic norm of the intensity conservation term by a linear norm:

$$E_{L2L1}(u, v) = \iint_{\Omega} |I_x u + I_y v + I_t| + \beta^2 (\|\nabla u\|_2^2 + \|\nabla v\|_2^2) dx dy \quad (2)$$

The idea is that this functional reduces the confidence in the conservation of signal intensity, relying more on the assumption of an elastic deformation. This leads to a better representation of elastic organ deformation in the vicinity of arterial signal fluctuations. The

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experimental validation was performed in the following way: Dynamic MR-imaging of both liver and kidney was performed under free-breathing conditions on the abdomen of two healthy volunteers, resulting in 1500 images for each volunteer. A second dataset was derived by applying retrospective cardiac gating (i.e. while respiratory motion is present, all images represent peak-systole) to serve as a gold standard. Subsequently, the registration error (i.e. registration based on the complete data vs. registration of the cardiac gated images) for both methods is compared.

3. RESULTS

As shown in figure 1 the proposed tracking algorithm performs significantly better in the upper liver and in particular in the vicinity of larger vessels, such as the hepatic arteries and the portal vein. With respect to performance, the $L^2 - L^1$ algorithm converged on average in 25ms with a typical end-to-end processing latency (since the beginning of the MR-slice acquisition to the output of the motion fields) of under 100ms. Both the convergence time and the latency are well within the requirements for real-time guidance [1]. Note, however, that the lack of differentiability of the proposed functional made an implementation that respects such constraints a particularly challenging task.

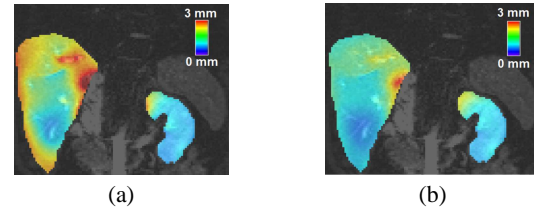


Fig. 1. Pixel-wise error with respect to their gold standard for the (a) Horn&Schunck and (b) $L^2 - L^1$ method in the presence of arterial pulsations.

4. CONCLUSION

The presented study proposes an improved MR-based real-time tracking method for respiratory motion. Compared to previous approaches, our method has shown increased robustness to in-flow / pulsation effects induced by the cardiac cycle. Additionally, the low end-to-end processing latency renders our method potentially suitable for real-time MR-guidance of HIFU and EBRT interventions in the abdomen, under free-breathing conditions.

5. REFERENCES

- [1] M. Ries et al., “Real-time 3D target tracking in MRI guided focused ultrasound ablations in moving tissues,” *Magnetic Resonance in Medicine*, vol. 64, pp. 1704–1712, 2010.
- [2] B.K.P. Horn and B.G. Schunck, “Determining optical flow,” *Artificial Intelligence*, vol. 17, pp. 185–203, 1981.