Three Dimensional Tracking of Tag Intersections in Tagged MRI

Y. Shimizu[1], X. Jin[2], A. Amano[1], T. Matsuda[1]

[1]Biomedical Engineering Lab., Department of Systems Science, Kyoto University, Kyoto, Japan, [2]Advanced Software Technology & Mechatronics Research Institute of Kyoto, Kyoto, Japan

Introduction

Tagged magnetic resonance imaging (MRI) offers the possibility to trace tissue deformation by creating planes of magnetic saturation [1]. Applying additional gradients prior to the scanning procedure, results in dark stripes in the image, indicating planes of signal decrease in a three-dimensional volume data. In the subsequently acquired time series, these planes bend out of shape corresponding to the deformation of the imaged tissue. Retrospective tracking of the tag surfaces then enables reconstruction of the deformation process. For the latter, an excessive number of algorithms exists [2], which are based on the temporal analysis of the volume data as a stack of two dimensional images. Each slice in the data set is treated independently from the others. Matching of the corresponding tag lines through the imaging planes is afforded in the final stage. This non-trivial task becomes the more complex the lower the spatial resolution in slice direction.

In this study, a tag tracking algorithm, based on energy minimization, was developed, which traces the tag-intersections, rather than the tag-lines. Connectivity of the intersection points through the slices is taken into account by considering the same as a set of points connected to a three dimensional mesh. Through this incorporation of the third spatial dimension into the temporal tracking, assignment of the correct tag-lines to a tag-surface becomes redundant.

Material & Methods

(a)

(b)

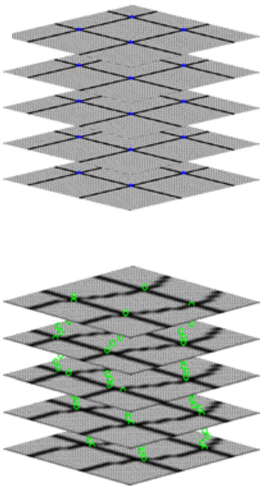

Fig.1: Simulation of two dimensionally tagged MRI data: (a) first time frame and template, (b) second time frame with deformed tag

Two artificial volume data sets were produced. In a matrix of size 50x50x20, with zero entries, the coordinates equaling two planes in x-direction and two planes in y-direction were set to 1. The resulting volume represents four intersecting tag planes in x- and y-direction, respectively and is equivalent to the first frame in a time series of two dimensionally tagged MRIs (Fig.1 (a)). The succeeding time frame was simulated by embedding four sinusoidally curved surfaces, orientated in x-, z-direction and y-, z-direction, respectively, into a volume matrix of size 25x25x25. The position of insertion was chosen according to the position of the planes in the template (Fig.1 (b)). The data was resized to yield a size of 50x50x20 and finally blurred by convolution with a Gaussian kernel of size 3x3 and $\sigma=1$. Both data sets, first and second time frame, were inverted and multiplied by the arbitrary value of 100.

The development of the tag intersection tracking algorithm was based on an algorithm, which is a modification of the active contour model [3], known as 'snake'[4]. Essentially, the aim is to minimize an energy function derived from the image and the template. Here, the template energy is the grid of intersection points: $E = \int E_{grid}[v(x,y)] - E_{image}[v(x,y)]ds$, where $E_{grid} = \sum_i \sum_j \beta(u_i - u_j)^2$, for all tag intersection points u_i and their connected neighbors u_j, when discretized. β defines the strength of attraction of the neighboring points to each other. The image energy was set equal to the gradient of a volume obtained by three dimensional normalized cross-correlation of the second frame with a 3x3x3 matrix representing an idealized tag intersection. As tag points moving through the image plane along the tag surface can not be traced, tag points were assumed to be fixed with respect to their z-coordinate. Minimization of the energy function above is achieved by iteratively solving the according set of linear equation using matrix inversion.

Results

Figure 2 shows that the intersection points of the template (blue) and the intersection points of the next time frame (green). The black crosses indicate the cross sections calculated by minimization of the energies given by the data and the template. The algorithm has successfully been applied.

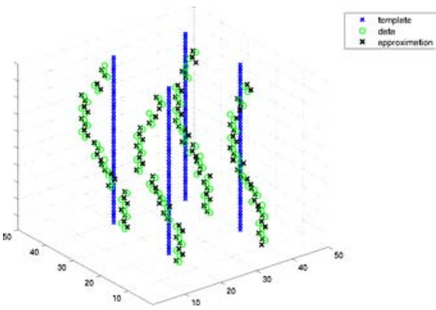

Fig.2: Tag line intersections of the second time frame (green) were traced (black) using the intersections of the first time frame as template (blue).

Discussion

Tagged MRI offers a valuable methodology for non-invasively setting tags for the tracking of mechanical tissue changes in time. For accurate evaluation, a high number of small tags and narrow temporal intervals are desirable. However, tag spacing as well as the number of images that can be acquired after setting the tags, are restricted due to physical properties of the tissue and sensitivity of the scanning process. Additionally, as in most clinical applications, time is an important parameter, so that a constant trade-off between improvement of the images and improvement of the analytical tools exists.

The algorithm presented above, uses a three dimensional approach to track the tag intersection points instead of the commonly traced tag-lines. Consideration of the third dimension during temporal tracking maintains the relation of the tags in the separate slices through the whole process. The tedious recombination of separately evaluated slices to a volume is spared. As additionally, the amount of data when handling tag intersection points is considerably less than when dealing with taglines, this methodology could serve as a fast initial estimation of deformation evolution. To also obtain information about the tag points between the intersections, keeping up the same advantages, our next aim is the extension of the algorithm to trace whole tag-surfaces.

References

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