Fast maximum intensity projection algorithm using shear warp factorization and reduced resampling

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Introduction

Maximum Intensity Projection (MIP) is the most widely-used algorithm for displaying volumetric angiographic data in MRI and CT. Generally MIP is implemented through ray casting and searching for the maximal intensity in that ray. At an arbitrary projection angle, the volumetric data are resampled using linear interpolation. The resampling process is time-consuming, particularly for large data sets associated with high resolution images and when a general desktop PC is used.

Since the depth information is discarded in projection, the data resampling along the ray direction is unnecessary, and MIP process can be accelerated accordingly. This paper reports a shear warp method that eliminates unnecessary resampling, allows efficient addressing, and shortens MIP time by ~10 fold.

Methods

The time-consuming components in a standard ray-casting MIP process (Fig.1a) are a) addressing to access the volume data not according to storage order, and b) resampling data using linear interpolation. A typical resampling kernel is a cube of 8 corner points that encompasses a point in the projection ray. The required number of multiplication in a linear interpolation is 24 in this case.

The resampling along the ray direction can be eliminated with a shear-warp algorithm, which can be expressed as a factorization of the viewing matrix into a 3D shear matrix multiplied by a 2D warp matrix (Fig.1b). The volume data (stacked slices in Fig.1) are first sheared according to the projection angle. An intermediate 2D projection image (with incorrect aspect ratio) is generated from the sheared data set. Then a final projection image (with correct aspect ratio) is obtained by warping the intermediate image according to the projection angle. Data resampling is limited to the sheared slice plane with a square kernel of 4 corner points. Correspondingly, the required number of multiplications in a linear interpolation is 8, a 3-fold reduction from the ray casting case. Computation time is further reduced because the same kernel coefficients can be used for all slices.

The amount of resampling within the sheared slices can also be substantially reduced by the fact that the linearly interpolated intensity is always smaller than the maximal intensity among the points in a resampling kernel. If the current maximal intensity along a ray is larger than the maximal intensity in an immediate kernel encountered by the ray, then resampling in that immediate kernel can be skipped. We found ~90% of kernels can be skipped in the MIP of an MRA data set.

In the shear warp algorithm, the projection process accesses the volume data in storage order after a 3D shear, therefore simplifying the addressing calculation. This allows efficient traversing through the volume data, and substantially boosts projection speed.

The problem with 90° shear is addressed by a preprocessing that transposes data matrix into three copies corresponding to three principal viewing directions, limiting effective projection angle to [-45°, 45°].

Results

The standard ray casting with linear interpolation and shear warp were implemented and compared on 3D MRA data set. Fig.2 shows the time performance of the two algorithms on a 256x256x60 data set. On average, the shear warp algorithm was 11 times faster than the ray casting, as measured on a PIII/450 56M RAM PC (TCL Co, Guongdong, China). The memory size required by shear warp, though bigger than that required by the standard ray casting, was much smaller than the RAM available on the modest PC. The shear warp and ray casting algorithm generated similar MIP images (Fig.3).

Discussion

The shear warp algorithm described in this paper speeds up MIP by 1) eliminating data resampling along projection direction, 2) skipping unnecessary resampling in the slice plane, 3) employing efficient addressing. The MIP time is reduced by a factor of 10 on a 256x256x60 data set. The time saving factor is bigger on a larger data set.

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