Concepts of Motion Detection and Correction in Medical Imaging

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Encoding consistency is a fundamental requirement for image formation. If it is violated, such as in case of motion or slow "shutter speed", image artifacts will occur. Many medical imaging modalities suffer from motion artifacts caused by violating encoding consistency. The presentation of these artifacts is determined by the underlying physical and algorithmic principles of image data acquisition, the timing and extent of motion relative to the imaging process, and the type of motion. Motion can be introduced by the patient (eg. CT, MRI, PET) or the modality/operator itself (e.g. US probe movement, MR imaging gradient vibration) or both (e.g. US). Even fast acquisition methods such as CT can suffer from motion artifacts. In this context, one should differentiate between intraacquisition motion (e.g. while a cardiac CT frame is acquired) and motion between acquisitions (e.g. between two diffusion-weighted MRI images or two CT perfusion time points). While the latter can often be fixed by image coregistration, intraacquisition motion violates the aforementioned encoding consistence and corrections can usually only be done in the raw data space and with knowledge of the appropriate motion model. Here, the simplest form is rigid body motion. It models motion as simple translation and rotation. A more generalized form is elastic body motion where each voxel in the original image gets arbitrarily shifted to a new position and sophisticated interpolation/approximations can be used to compute voxel locations on the new locations. In a very generalized form, the following steps occur at an imaging acquisition in the presence of motion: (static original image) → (spatial warping due to motion) → (modulate with detector sensitivity) → (transform image into rawdata space: e.g. Fourier or Radon space) → (readout raw data for encoding step: e.g. inverse grid k-space trajectory or cone beam projection) → (write out data). The detection of motion can be done either with the imaging modality itself (e.g. MR navigators, RF pickup coils, RF coil loads), external tracking (EM probes, stereovision, structured light, time of flight) or hybrid systems (e.g. MR to correct PET). In the community there are generally two approaches used to correct for motion: retrospective and prospective correction, although the latter is a misnomer and is better called adaptive correction. With retrospective correction the data are acquired first and thereafter an attempt is made to correct for motion. This approach is usually more widespread as it does not require any modification of the data acquisition procedure of the modality. However, this approach usually leads to incomplete or excessively sampled regions of raw data space. It also deals poorly with through plane motion and in MRI with spin history effects. With adaptive motion correction, an attempt is made by the modality to keep up with the patient's motion and "lock" the slice plane to the patient's anatomy even if the patient is moving. Here, it is paramount that the motion tracking occurs almost instantaneously and without any lag as the goal of adaptive motion correction is to avoid/minimize errors in encoding consistency and "damage" to the raw data. To date, adaptive motion correction is only available for rigid body motion correction but this does not mean a solution will be available some time in the near future. Clinically, motion is without doubt one of the last big challenges in medical imaging. Patient motion can lead to repeat scans thus lengthening overall study duration, requirement for sedation, or full repeat scans at another point in time. Even in neuroimaging, a substantial amount of scans are corrupted. It is estimated that 1-2 studies per day and per scanner are corrupted, which can lead to considerable economic burden. An estimate of several hundred thousand dollars in lost revenue per scanner has been reported recently. Radiologists are often not even aware of the gravity of the problem as corrupted scans are not sent to PACS. Particularly in an era where high patient throughput and overall costs for imaging studies is an item of big public concern, lost scan time due to patient motion is gaining even more relevance.

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