ADAPTIVE CONTROL OF COMPUTED TOMOGRAPH ANGIOGRAPHY

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Abstract: In this paper, an adaptive scheme is proposed and tested for a next generation Computed Tomograph Angiography (CTA). The purpose of the control is to estimate the contrast bolus position so its variations can be compensated by controlling the patient table. This improves the imaging quality and reduces the amount of harmful contrast injection and radiation exposure. The convergence result has been achieved and the experimental results are very promising. *Copyright C 2006 IFAC*

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1. INTRODUCTION

In the recent years, CT (Computed Tomography) angiography has become one of the most popular medical diagnostic tools (Rubin *et al.*, 1998) due to its non-invasive nature and faster scanning capabilities. In CT angiography, contrast material is often administrated to allow a narrow temporal window to obtain optimal visualization of vessels, lesions and tumors (Sheafor *et al.*, 1998; Tublin *et al.*, 1999). The quality of scans depends on the ability to synchronize patient table position with the relatively narrow aperture of the imaging system during propagation of a contrast bolus after intravenous injection. Contrast bolus synchro-

nization is achieved by using arrival monitoring with CT fluoroscopy. However, arrival monitoring synchronizes only the initial peak of contrast and the subsequently assumed linear table velocity becomes problematic as time increases.

Peak bolus velocity is rarely uniform. Therefore synchronization of the bolus with a fixed, preset table transport often results in less-desirable vascular enhancement. Lack of synchronization may be more problematic when scanning speed is fast, contrast volume is small, injection rate is high (leading to reduced peak duration), and/or variable vessel lumen diameter. Even for a normal individual, it is common that the contrast bolus velocity is rapid in the torso and relatively slow in the legs. Moreover, if asymmetric peripheral

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Table 1. Blood velocity variation for normal male adult.

Blood Velocities (in artery)	Peak Velocity (cm/sec)	Mean Velocity (cm/sec)
Aorta	150 ± 30	27 ± 8.9
Common lliac	$125 \pm NA$	13.5 ± 4.0
External lliac	119 ± 21.7	10.5 ± 5.0
Common Femoral	114 ± 24.9	10.2 ± 4.8
Superficial Femoral	90.8 ± 13.6	8.8 ± 3.5
Popliteal	68.8 ± 3.5	4.9 ± 2.9
Posterior tibial	61 ± 20	4.4 ± 3.3
Dorsalis pedis	NA	3.6 ± 3.8

vascular disease exists, there may also be substantial variability in flow velocity between the opposite legs. Scanning too early may result in overestimation of stenosis, while scanning too late may result in venous opacification. The published data shows that even in a normal person, the bolus velocities at different body section can vary by 8 times, see Table 1. Obviously, adaptive bolus chasing techniques are relevant to CT angiography because of the impact on image quality, as well as the need to limit contrast dose and radiation exposure.

The aim is to develop an adaptive bolus chasing CT angiography technique. The idea is illustrated in Figure 1. The control system consists of an imaging acquiring, processing and reconstruction part, an adaptive algorithm to estimate and predict future bolus position and a controller that moves the patient table to compensate the bolus variations. Works reported here are the algorithm development and experimental results in a clinical environment based on the actual patients data. The convergence of the algorithm has been
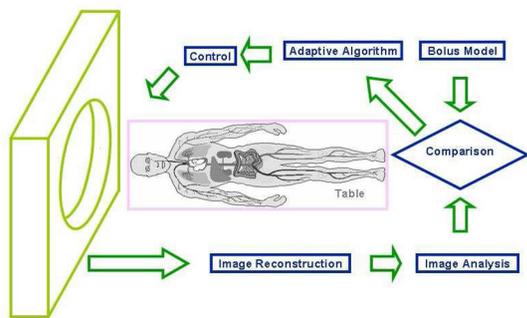
Fig. 1. Control scheme illustration

2. BOLUS DATA EXTRACTION

Adaptive control of a bolus chasing CTA requires an understanding of contrast bolus dynamics under normal and diseased conditions. Properties such as ECG gating delay, peak bolus velocity,

and average bolus velocity are essential to development of a robust adaptive control system. Furthermore, variations in contrast bolus dynamics secondary to vascular disease categories must be understood to allow for experiments under realistic clinical conditions.

While a through investigation of the bolus dynamic is beyond the scope of this control paper, actual patient data is necessary. The patient data was obtained from routine diagnostic peripheral angiograms on a Siemens AXIOM-Artis utilizing iodinated contrast agent. The scans are generally performed at 15 frames per second (fps) and the sampling rate for the ECG signal is 400 samples per second. The data sets were saved in the Digital Imaging and Communications in Medicine (DICOM) Format, a medical standard in most modalities for transfer of images, movies, and other diagnostic data. Each DICOM patient data file was opened with RUBO. Then, the movie information was extracted and saved as a Windows Media Video Clip (AVI). The ECG data (native format is in the hexadecimal base) was manually retrieved from the XML file. The algorithm developed in LabVIEW extracts every frame in the cine sequence and processes these images for analysis of bolus dynamics. First, the image was converted from a RGB image (pixel is associated with three intensity values: Red, Green, Blue) into a gray scale image (pixel with only one intensity value). Then, the image was defined to a region of interest without significant interfering features. A process called Digital Subtraction was used to remove any stationary artifacts. For example, if each pixel in the current frame is subtracted from its counterpart pixel in the mask frame, stationary objects in the sequence will be suppressed. This will increase the conspicuity of the moving structures, i.e., the contrast bolus, in each frame of the sequence. Figure 2 illustrates the effects.
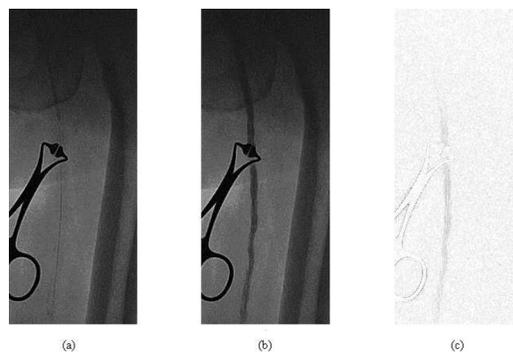
Fig. 2. (a) First frame of a cine scene, (b) the nth frame and (c) the resultant subtracted image

Over one hundred of patient data sets were studied. A representative ECG signal and bolus peak position as functions of time is shown in Figure 3. Alignment of the bolus propagation and the ECG