MOTION DETECTION IN FLUOROSCOPIC IMAGE AND ITS APPLICATION TO CATHETER MARKER TRACKING

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ABSTRACT

The preferred treatment for cerebral aneurysms is currently endovascular intervention. The real-time navigation of tools is conducted with fluoroscopic image guidance. This imaging technology is composed of single or biplane panels mounted on C-arms with multiple orientations capability. In theory, simultaneous biplane image acquisitions allow for a 3D reconstruction of the object of interest, in this case, interventional devices (guide wires, catheters, coils). These devices must be precisely located and tracked in real-time in the two fluoroscopic images for 3D reconstruction. However, the X-ray output is adjusted to reduce radiation exposure which results in low contrast and low resolution images. Thus, tracking algorithms require numerous enhancement treatments which are time consuming. Many approaches on tools segmentation and tracking have been proposed in literature with highly successful results, but no author has yet achieved a real-time process. This constraining objective is of utmost importance for effective clinical implementation of 3D road-map guidance. A new solution is proposed to combine and restrict the tracking algorithms to motion detected regions in the fluoroscopic image sequences. Motion regions are located with simple and fast fluoroscopic subtraction and digitized using threshold based on the standard deviation. This technique is tested on catheter markers tracking from *in vivo* fluoroscopic images acquired during cerebral embolization of aneurysms. The effective tracking of multiple markers was benchmarked at 3 to 5 frames per second. The motion areas restriction of algorithms can be implemented to other tools' tracking to eventually achieve a successful real-time 3D road-map guidance.

INTRODUCTION

A cerebral aneurysm is a vascular disease caused by vessel wall defect, mainly at branch bifurcations. The weakening of the tissues leads wall expansion, forming a balloon-like abnormality. These aneurysms may rupture, an event that is often dismal due to rapid rise of intracranial pressure, which causes direct brain damage and reduced blood supply.

The preferred treatment for a brain aneurysm is the embolization of the balloon pouch with platinum coil. Open surgery is the alternative treatment, but submits the patient to larger risks [1]. An embolization procedure is conducted with endovascular tools inserted through major arteries. A guide wire is first inserted for its flexibility and navigation capacity. A micro-catheter is then threaded on the guide to serve as a conduit for the platinum coil or for modeling tools, such as balloons and stents. These tools are used to control the coil deployment. All endovascular tools' movements inside the patient are monitored by fluoroscopic imaging, used as video feedback. This low dose x-ray technology consists of source-detectors mounted on C-arms that allow limited angular adjustment. Most setups for cerebral aneurysm embolization are composed of two simultaneous fluoroscopic views (biplane).

Although the embolization of an aneurysm is the preferred treatment, the morphology of the aneurysm may yield this intervention difficult, or even unfeasible. The fluoroscopic angular limitations hinder an acceptable working plane of view. Some interventions are aborted due to limited viewing. Although a rotational scan at the beginning of the intervention produces a three dimensional representation of the cerebral vascular tree, the tools positioning may be difficult to interpret during real-time work from biplane fluoroscopic views. An example of difficult viewing may come from blood vessel overlapping, causing false interpretation of a tool position.

The new technology of digital panel detectors has lower position errors due to the absence of distortion inherent to image intensifiers. With these more precise systems, novel research effort has produced digital image enhancements that help the physician during the intervention. These new image processing softwares register the 3D vascular tree within current fluoroscopic views reducing the use of contrast agent normally used to opacify blood vessels in x-ray acquisitions [2-4]. They also allow (to a certain degree) the understanding of the tool's 3D location. Nevertheless, the solution to a full understanding of the tool's location resides in a digital three dimensional representation of the scene in real time, providing projections that may be physically impossible to obtain due to angulation limitations of the C-arms. This ambitious objective is limited by low images quality processing at high speed in a video-like display. Many authors have worked on automatic tracking of single guide wires in biplane fluoroscopic images [5-10] or

catheter localization and tracking [11]. Some proposed algorithms have high success rate but failed in near real-time image processing. The computational requirements are too demanding for a single computer. In a recent paper, Takemura et al. [11], presented a motion based tracking algorithm of microcatheter markers. This technique is less computationally demanding and can be implemented as a near real-time image process.

In this paper, we propose the implementation of a motion detection algorithm to minimize the computational requirements of robust tool tracking in fluoroscopic images. This procedure allows near real-time 3D visualization of endovascular tools during embolization of cerebral aneurysms. A proof of concept is made using an effective tracking of multiple microcatheters in *in vivo* fluoroscopic biplane images.

METHOD

Motion in digital image sequences can be defined as a local change between two frames. The change originates from an object's last and new positions. Bigger objects in motion generate local changes at their contour normal to the displacement vector. Thus simple subtraction between two succeeding images can highlight motion. The change sign indicates if the highlighted region is the last or the new object's location. Takemura et al. [11] proposed an algorithm based on this property. A smoothing effect (4 frames average) is added to suppress image noise that can trigger false motion detection. Because the object of interest is so small (microcatheter markers), it appears entirely in the subtracted image. Marker segmentation is then possible with a simple object match filter to highlight the probable location. Thus markers are only detected if they are in motion. When an already detected marker stops moving, its position becomes stationary. A smaller region of interest (ROI) on each marker reduces effectively the computational time.

Motion Detection

The smoothing of motion detection may reduce signal-to-noise ratio but also prevents certain slow movement detection. It is caused by the average calculation that smoothens object edges. A quick validation of a few image subtraction formulas shows that for our database (15 frames/sec fluoroscopic sequences), the subtraction from the current frame of the second preceding frame can detect slow and fast moving endovascular tools. The formula is shown in eq. 1.

$$s_i(x,y) = f_i(x,y) - f_{i-2}(x,y), \forall\, i = 3,\ldots,n \quad (1)$$

where s_i is the subtracted image at frame *i* and f_i is the fluoroscopic image frame at time *i*. The sequence has *n* frames of size *x* by *y*.

Regions of motion are drawn by a threshold operation based on the subtracted image standard deviation. The updated standard deviation can effectively separate motion and noise.

Microcatheter Markers Detection

Microcatheters are not visible on fluoroscopic images because they are not radiopaque enough compared to their size. A radiopaque ring is placed at the microcatheter tip and at a precise distance from it. These rings appear as dots on fluoroscopic images and serve as tool targets. Takemura et al.'s method [11] to detect these targets is based on object matching in subtracted images. Thus no marker is detected unless it is in motion. Because the prior locations of markers are not always known or reliable, a novel detection algorithm has been developed for the detection of markers on fluoroscopic images. This algorithm uses the image's first derivative, the gradient, to enhance small round-like dark spots. It is based on the property of gradients around a circle object: they all point to the circle's center. The detection is effective but computationally demanding. A 512 x 512 fluoroscopic image is processed in a few seconds; too long to be used in near real-time implementation.

Real-time Microcatheter Markers Tracking

Considering the computational requirements of robust microcatheter detection, a fast tracking algorithm is possible if the image processes are applied to a small ROI. This ROI is centered on pre-identified markers and adapted to nearby motion detected regions. The complete markers tracking program architecture is :

1. The first image is completely analyzed to locate initial markers. This initialization takes a few seconds.
2. Detected markers are tracked in real time on each video frame by triggering a local search around previous positions when motion is detected locally.
3. Each new frame contour is motion monitored to detect the arrival of new objects in the scene.

Experiments

The detection and tracking algorithms of microcatheter markers were tested on fluoroscopic sequences saved during cerebral aneurysm embolization interventions. This data collection was conducted anonymously with approval from CHUM Notre-Dame Hospital's and École de technologie supérieure's ethics committees. Saved sequences have 300 or less frames of up to 20 seconds of fluoroscopic biplane video. The image acquisition is set to 15 frames per seconds to minimize the patient x-ray exposure without compromising the visual feedback.

Experiments were conducted to evaluate the performance and the computer time consumption of the proposed method. The used computer has a dual processor of 2.13 GHz and 1 GB of RAM. The development platform is Matlab.

RESULTS

Figure 1 illustrates a single fluoroscopic image of two overlapping guide wires inserted in microcatheters. The robust marker enhancement filter results are presented in Figure 2. Markers are shown brighter, even though they coincide with a guide wire. The detection of markers in the 512 x 512 fluoroscopic image took 4 seconds. Each marker position was updated frame by frame following the sequence. The process rate of new frame is between 3 to 5 images per second. This variation is explained by the variable number of markers to track.

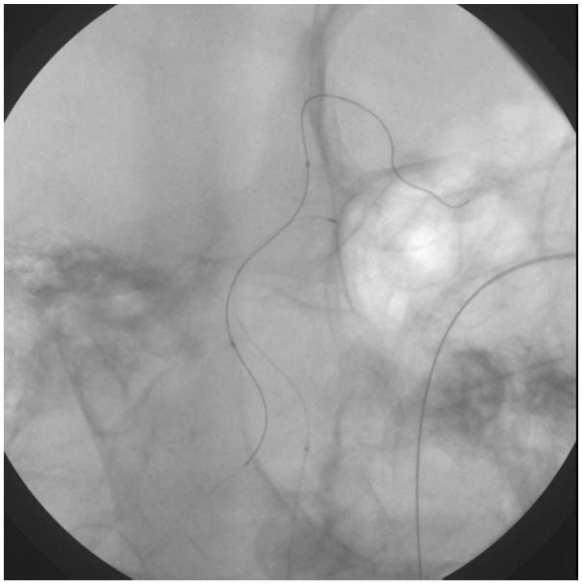

Figure 1: Fluoroscopic image

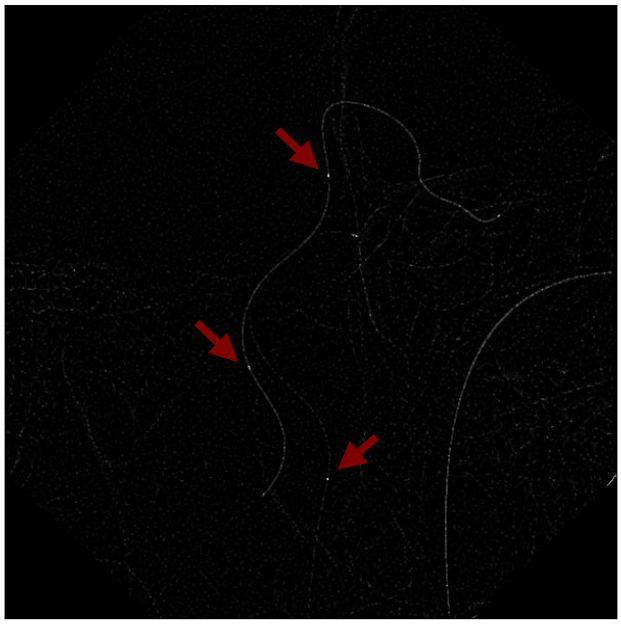

Figure 2: Marker enhancement

Figure 3 presents in detail a single marker tracking. The steps are : (a) the second preceding view, (b) the current view of the marker, (c) the detected motion and (d) the marker enhancement filter. The motion regions are the last and new positions of the marker. The new highlighted position in Figure 3(d) corresponds to the marker's actual position in Figure 3(b). The binary motion regions of Figure 3(c) used as a filter mask effectively reduces the computation time of the marker enhancement filter while maintaining a robust tracking performance.

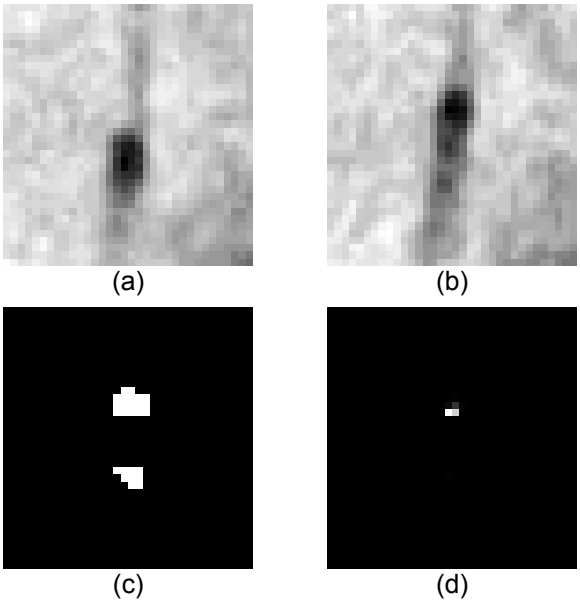

Figure 3: Marker tracking

DISCUSSION AND CONCLUSION

The preferred treatment for cerebral aneurysms is currently endovascular intervention. The real-time navigation of tools conducted with fluoroscopic image guidance is not always possible due to angular view limitations. In theory, simultaneous fluoroscopic biplane image acquisitions allow for a 3D reconstruction of interventional devices that could help the physician during embolization procedures. These devices must be precisely located and tracked in near real time in the two fluoroscopic images for usable 3D representation support. The near real-time constraining objective is of utmost importance for effective clinical implementation of 3D road-map guidance. A new solution is proposed to combine and restrict the tracking algorithms to motion detected regions in the fluoroscopic image sequences. Motion regions are located with simple and fast fluoroscopic subtraction and digitized using a threshold based on the standard deviation. The technique was tested on catheter markers tracking on *in vivo* fluoroscopic images acquired during cerebral embolization of aneurysms. The effective tracking of multiple markers was benchmarked at 3 to 5 frames per second, with an initialization process of 4 seconds to locate devices. This processing time is acceptable considering experiments were conducted on a developmental platform with no code optimization. The motion region restrictions to image processes can be implemented to other tools' tracking to eventually achieve a successful near real-time 3D road-map guidance of the complete endovascular scene.

ACKNOWLEDGEMENTS

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