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Workflow for the use of a high-resolution image detector in endovascular interventional procedures

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Abstract

Endovascular image-guided intervention (EIGI) has become the primary interventional therapy for the most widespread vascular diseases. These procedures involve the insertion of a catheter into the femoral artery, which is then threaded under fluoroscopic guidance to the site of the pathology to be treated. Flat Panel Detectors (FPDs) are normally used for EIGIs; however, once the catheter is guided to the pathological site, high-resolution imaging capabilities can be used for accurately guiding a successful endovascular treatment. The Micro-Angiographic Fluoroscope (MAF) detector provides needed high-resolution, high-sensitivity, and real-time imaging capabilities. An experimental MAF enabled with a Control, Acquisition, Processing, Image Display and Storage (CAPIDS) system was installed and aligned on a detector changer attached to the C-arm of a clinical angiographic unit. The CAPIDS system was developed and implemented using LabVIEW software and provides a user-friendly interface that enables control of several clinical radiographic imaging modes of the MAF including: fluoroscopy, roadmap, radiography, and digital-subtraction-angiography (DSA). Using the automatic controls, the MAF detector can be moved to the deployed position, in front of a standard FPD, whenever higher resolution is needed during angiographic or interventional vascular imaging procedures. To minimize any possible negative impact to image guidance with the two detector systems, it is essential to have a well-designed workflow that enables smooth deployment of the MAF at critical stages of clinical procedures. For the ultimate success of this new imaging capability, a clear understanding of the workflow design is essential. This presentation provides a detailed description and demonstration of such a workflow design.

Keywords

MAF; high resolution detector; angiography; workflow; x-ray imaging; endovascular image-guided interventions; CAPIDS

1. INTRODUCTION

During endovascular interventions, the interventionalist guides a catheter and an endovascular device to the pathological sites using x-ray image guidance. These endovascular procedures are done using devices (such as stents, balloons, coils, snare

devices, etc.) which are manipulated using catheters. The size of these devices are of the order of millimeters with structure details smaller than 100 microns and these devices require sub-millimeter placement accuracy. Hence, high resolution imaging capabilities are essential for an efficient, accurate, and successful endovascular interventional procedure [1].

Our group has developed a detector, designated the Microangiographic Fluoroscopic (MAF), with high resolution over a small field-of-view. This MAF detector is installed on an automatic changer and hence can be inserted in front of the standard flat-panel detector when high resolution is needed during angiographic or interventional vascular imaging procedures [2]. Also, MAF can be used without a significant delay in the procedure, as the MAF swings into place in front of the standard AP fluoroscope. Initial patient studies have demonstrated that the use of the high-resolution MAF detector at selected points in a procedure may play an important and decisive role in clinical studies [3]. With the use of the MAF detector, tiny features of the devices such as stents, small movements of the microcatheters and coils can be seen. This information contributes in making confident decision by the neurosurgeons during an intervention. A clear understanding of the workflow design for using these detectors is critical to the ultimate success of this new imaging capability.

2. METHODS AND MATERIALS

A new x-ray, high-resolution detector, the Microangiographic Fluoroscope (MAF) was incorporated into a standard angiographic C-Arm system as shown in Fig 1. The detector is attached to the gantry using a specially designed changer onto the AP C-arm of an x-ray biplane angiographic unit (Toshiba Medical Systems, Tustin CA). The detector can be moved to the deployed position in front of the Flat Panel Detector (FPD) during a sensitive part of an intervention which requires high resolution and the MAF can act somewhat like a surgical microscope. Because of the MAF's high resolution, its alignment is critical and must be done carefully with a specially designed test tool so that the site of pathology remains in the center of the displayed field of view for both detectors. The collimators are automatically adjusted to the active area of the MAF to limit the dose to the patient. A touch sensor at the front of the MAF detector holder causes the entire imaging unit (FPD and MAF detector) to retract upon physical contact in order to avoid collision of the MAF detector with a patient or other objects on or near the table.

2.1 Micro Angiograph Fluoroscope

Figure 2 provides an external view of the custom-built MAF and Figure 3 shows a schematic of its components which are described extensively in [4]. The MAF is a region of interest x-ray imaging detector capable of real-time imaging (up to 30 fps) for both fluoroscopic and angiographic applications. The detector has a round FOV with 3.6 cm diameter and 35 micron pixels. The structured scintillator with non-reflective front surface (HR type) provides high spatial resolution. It consists of a CCD camera coupled to a Gen 2 dual-stage micro-channel plate light image intensifier (LII) through a fiber-optic taper. The LII component of the MAF has a large variable gain, allowing the use of the detector at the very low exposures characteristics of fluoroscopic ranges and while maintaining superior image quality with approximately 2–3 times the resolution of standard X-ray detectors. The

availability of high dynamic gain and low instrumentation noise allows us to operate MAF in quantum noise limited region even at the exposures lower than the normal fluoro exposures.

2.2 Control, Acquisition, Processing and Image Display Storage (CAPIDS) System

The MAF detector can be operated in various imaging modes such as fluoroscopy, roadmap mode and DSA and is controlled using LabVIEW-based software, designated the Control, Acquisition, Processing, Image Display and Storage (CAPIDS) System [5]. In the beginning of the procedure, information about the patient is entered into the CAPIDS system and the exposures/acquisitions i.e. fluoroscopy, roadmap mode and DSA are saved under the patient id. The tube parameters and the positional information of the C-arm (e.g. LAO/RAO, CRA/CAU angulation, SID), table (e.g. table height, position) and the focal spot used (small, medium or large) is read from the CAN-bus and is automatically updated on the CAPIDS system. In order to provide the interventionalist with a better image, the CAPIDS system offers real time processing such as temporal filtering and window/level settings.

The CAPIDS system also enables automatic control of the MAF detector gain so as to provide the interventionalist with the best possible visualization which allows the interventionalist real time acquisition, processing, and display of the high resolution images.

The user friendly interface along with the CAPIDS system's well-implemented automation of the radiographic procedures should make conduct of complex EIGIs simpler for the neurosurgeons or interventionalists.

2.3 High Definition Mode (HD Mode)

Normal fluoroscopy uses the medium focal spot (0.5mm) to reduce tube wear. In order to reduce the loss of spatial resolution due to the size of the focal spot during normal fluoroscopy, the interventionalist can opt for using what we designate the HD mode. In HD mode, a small focal spot is chosen manually with appropriate tube parameters and the DA foot pedal is used to produce x-rays at higher than standard fluoroscopy rates. The HD mode uses a small focal spot (0.3) for better resolution and a higher dose rate to reduce the quantum noise which achieves increased CNR [6]. Though the exposure rate is increased, it has been shown that the integral or effective dose for the MAF is much lower than that for a conventional 20×20 cm field of view of a flat panel detector [7]. The HD mode is meant to be used during critical portions of an interventional procedure, such as during the actual stent deployment.

3. RESULTS AND DISCUSSION

In order to develop a workflow design, we simulated the situation as occurs during clinical procedures using a skull phantom with an aneurysm (see Fig 4). Since the aneurysm is inside the skull phantom, it is not visible in the figure (Fig 4)

The complete workflow for use of the high-resolution MAF detector for neuro-vascular interventions is described step by step:

- The site of pathology is located using a standard Flat Panel Detector (FPD).

- The catheter is inserted in the femoral artery, and then threaded under fluoroscopic guidance to the site of the pathology (such as an aneurysm).
- The pathology is brought to the center of the FPD FOV (see Figs 5 and 6).
- Using automatic controls, the MAF is 'deployed' in front of the FPD and positioned as close to the patient as possible to minimize geometric unsharpness (see Fig 7). The same frontal monitor display inside the angio room is used for the FPD (see Fig 8) and is changed electronically to display the MAF image for the interventionalist using the remote video switch.
- The 'Automatic exposure control' of the angio system is turned off because otherwise the system will choose very high exposure parameters as the MAF detector is in the FPD's field of view. The exposure parameters for the MAF are then controlled manually.[8]
- Now, the aneurysm should be at the center of the MAF because the aneurysm was previously at the center of the FPD and the MAF center was aligned with that of FPD.
- Fluoroscopy proceeds (Fig 9) with selectable temporal filtering weight. Window and level can be adjusted appropriately to get a better display of the acquired images.
- Standard fluoroscopy uses the medium focal spot (0.5 mm). However, the MAF can be operated in High Definition (HD) fluoroscopic mode which can use the small focal spot and can provide an increased fluence rate and hence a better contrast-to-noise (CNR). Thus, the HD mode can have the advantage of effectively improving the CNR with reduced geometric unsharpness.
- **DSA** - A DSA run is done under CAPIDS. At the end of the DSA run, CAPIDS enters the playback mode automatically (Fig 10). All the DSA runs are stored in an automatically created and uniquely named file and can be easily accessed by clicking on the "previous run" tab (right above the "Image Processing Controls").
- **ROADMAP** - High-resolution roadmap display with the ability to change the mask is also implemented in the CAPIDS software. CAPIDS is designed so that there are three ways to choose the roadmap:
 1. 'Fluoro' roadmap - A roadmap is acquired by doing a fluoroscopic run. In this method, CAPIDS is used in 'roadmap' mode with 'new bone mask' and 'new roadmap' options checked (Fig 11). Then, contrast agent is introduced under fluoroscopic exposure. Stopping the fluoroscopic exposure and then pressing the foot switch again will display the roadmap.
 2. Selection of the roadmap from current DSA run - This can be done in two ways. First, the automatic selection of the roadmap by CAPIDS is done using the peak mask method. This is a default roadmap chosen by the program where the interventionalist does not specify a particular mask of his/her own choosing. The second way is to choose a particular frame of a

DSA run by clicking on the 'save mask' button (right on the top of the 'EXIT' button). (Fig 10).

3. Selection of the roadmap from previous DSA runs - If the interventionalist wants to choose a previous DSA run as roadmap then that particular run can be loaded into 'playback mode' (Fig 10) by choosing that run from the list of 'previous runs'. Once loaded into playback, we again have the same two options for choosing roadmap as explained above in 2.

- Once the roadmap is chosen, it can be implemented by taking fluoroscopic images under 'roadmap' mode (Fig 11).
- If the use of the MAF detector is no longer needed, the MAF is moved back into the park position using the automatic controls.
- The display inside the room is again manually switched back to the Toshiba system display of the FPD once the MAF is moved into the park position.
- The MAF detector can again be moved in front of the standard FPD, whenever higher resolution is needed during the procedure. It takes only 4–5 seconds to move the MAF to deployed position or park position.

In order to integrate the MAF into a total commercial system and to also make workflow even smoother and less complicated, important updates need to be completed in the present set-up. Some of these updates are mentioned below:

- A redesign of the MAF holder is required in order to avoid any interference by the table or hanging screen displays in the angiographic procedure room. Also, appropriate sensors should be installed to provide warning and to avoid any collisions.
- There should be an automatic switch which changes the display inside the angiographic procedure room to 'MAF display' the moment MAF is deployed and then brings the displays back to the Toshiba system once the MAF is moved back to the park position.
- Currently, x-ray tube parameters for the MAF are chosen manually. Hence, there should be an 'automatic exposure rate control' for the MAF like there is for FPD.
- It also would be advantageous to have standard fluoroscopy modified in such a way that when the MAF is deployed, the small focal spot is automatically used with appropriate tube parameters so that there would be no need for a separate 'HD fluoro' mode.
- When using the bi-plane system, a bi-plane acquisition workflow should be implemented to provide roadmaps in both the MAF and FPD planes.
- A file structure integrating both MAF and FPD run files should be implemented for use with bi-plane systems.

4. CONCLUSIONS

The rapid advances in the field of endovascular image guided interventions (EIGI) have led to the increased demand for improved quality in medical imaging. Our group developed a detector, the Microangiographic Fluoroscopic (MAF), with high resolution over a small field-of-view. The MAF is attached to the C-arm of a Toshiba system and is able to be deployed in front of the standard FPD when detailed information or higher resolution is required during these procedures. As a result, better and quicker treatment and more accurate diagnoses are expected to occur with the use of such an automated high resolution, micro-angiography fluoroscopy (MAF) medical systems. However, in order to make best use of the imaging capability available, there should be a clear understanding of the workflow needed while using this dual-detector system. Hence, the workflow design is reviewed for the use of high-resolution ROI detectors in clinical neurovascular studies. Such a workflow design enables the optimal usage and staff acceptance of this new modality.

Acknowledgments

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Fig. 1.
Clinical set-up of MAF which here is shown in deployed position in front of the FPD.

Fig. 2.
External view of the MAF with cover removed.

Fig. 3.
Schematic of Micro Angiographic Fluoroscope (MAF).

Fig. 4.
Skull phantom with an aneurysm placed inside. The phantom is held down by tape.

Fig. 5.
MAF in parked position to side of FPD.

Fig. 6.
FPD image of skull phantom.

Fig. 7.
MAF move to the 'deployed' position

Fig. 8.
Monitor display inside the angio room

Fig. 9.
CAPIDS display in fluoro.

Fig. 10.

CAPIDS is used to take a DSA run. After the DSA run, CAPIDS automatically enters the playback mode showing the complete run.

Fig. 11.

The roadmap shown here corresponds to the particular frame of DSA run shown in Fig 10.