A Navigation Console to Steer Magnetic Instruments Under Radiological Guidance for Neuro-Vascular Interventions

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May 31, 2022

A navigation console to steer magnetic instruments under radiological guidance for neuro-vascular interventions

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INTRODUCTION

The gold-standard for treating some neurovascular diseases such as ischemic stroke is an effective and minimal invasive endovascular technique. The primary instruments used are catheters and guidewires that are inserted into the vasculature through a small incision at the groin [1]. Some instruments have a curved tip allowing for easier access of different vessels as they bifurcate and are navigated by pushing, pulling, and rotating. In cerebrovascular interventions, interventional neuroradiologists are often faced with tortuous and complex anatomies that can be challenging to navigate and require a high level of skill and expertise [2].

An alternative to manual catheter and guidewires is a robotic approach using robotic magnetic navigation (RMN). In RMN, magnetic instruments composed of a flexible magnetic tip are redirected by the external magnetic field generated by a magnetic navigation system (MNS) [3]. In neurovascular radiology, where the instruments are navigated under radiological guidance, x-ray images of the patient anatomy and the instruments are displayed on a monitor. Under these circumstances, the steering of magnetic catheters and guidewires can be challenging, because they are 3D objects moving in a 3D environment, whereas the operator is provided a 2D image on a 2D display**.** Companies such as Stereotaxis make use of graphical representations of the magnetic field, the magnetic instrument, and the patient anatomy to help the operator in making the mental transformations [3]. Adding visual cues such as graphical overlays or a separate monitor have the potential to divert the doctor's gaze away from the x-ray image. This can lead to loss of focus and potentially increase risk. In this work, we propose a new interface that allows the steering of magnetic instruments without the need of additional visual feedback other than the already available 2D fluoroscope image.

MATERIALS AND METHODS

In radiological interventions, the emitter and collector of the x-ray fluoroscope are often rotated around the patient to obtain more favourable views (α and β in Fig 1(a)). Hence, the coordinate frame centered on the x-ray image is generally not aligned with the coordinate frame of the MNS (subscripted as *mns* and *xray* in Fig 1(a)). For intuitive handling, it is crucial to define the field inputs in the fluoroscope's frame of reference.

This allows the user to steer the magnetic instrument in the image without having to maintain a mental model of all the necessary geometric transformations. As a consequence, the orientation of the imaging device must be constantly updated. This can be achieved by adjusting the fluoroscope orientation manually or by accessing the angles α, β directly from the imaging device or from sensors attached to it.

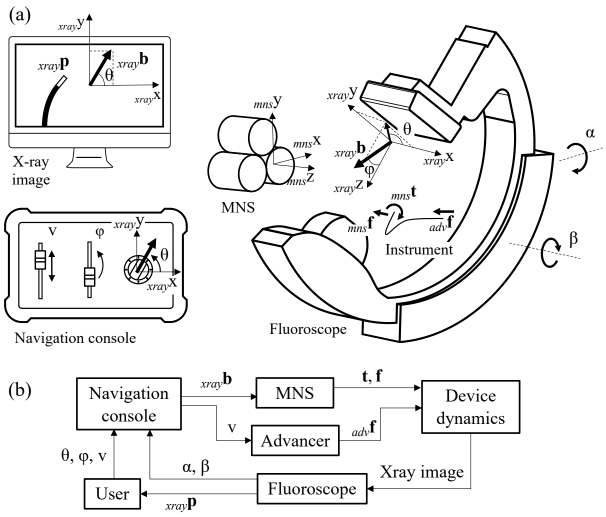

Fig 1 (a) The magnetic instrument is steered with the magnetic field ${}_{xray}\mathbf{b}$ generated by the MNS and inserted by the advancer at speed v. The field induces torques and forces ${}_{mns}\mathbf{t}$ and ${}_{mns}\mathbf{f}$ acting on the magnetic tip of the instrument and the advancer applies a pushing force on the proximal side ${}_{adv}\mathbf{f}$. The magnetic instrument is imaged with an x-ray fluoroscope that provides visual feedback. The user steers the instruments with the navigation console by changing the magnetic field ${}_{xray}\mathbf{b}(\theta, \varphi)$ in the fluoroscope's frame of reference. (b) Block diagram of the control scheme. Inputs to the navigation console from the user are θ, φ and v.

As a second measure to make steering more intuitive, we introduce the concept of absolute field control. By absolute field control, we rotate the magnetic field in absolute coordinates rather than changing the direction in relative steps. To this end, we developed a navigation console that maps the orientation of the user inputs one-to-one to the orientation of the magnetic field.

The new interface was tested in the setup seen in Fig 2(a). The MNS used is a three-coil electro-magnetic navigation system (eMNS) capable of generating magnetic fields at a magnitude of 25 mT, 20 cm away from the coils' surface. The magnetic field induces torques on the magnets embedded in the instruments, causing their tip to align in the direction of the applied field. A magnetic catheter and a magnetic guidewire are navigated inside a silicone phantom model (Trandomed 3D Inc.) in the aortic arch and the M1 coronary arteries. The model is filled with a water-soap solution and navigation is performed under no-flow condition. The magnetic instruments are inserted and retracted by a remote-controlled robotic advancer unit and imaged by a C-arm fluoroscope (Ziehm Imaging Inc.). During instrument navigation, the operator is not provided with any visual feedback of the current magnetic field direction.

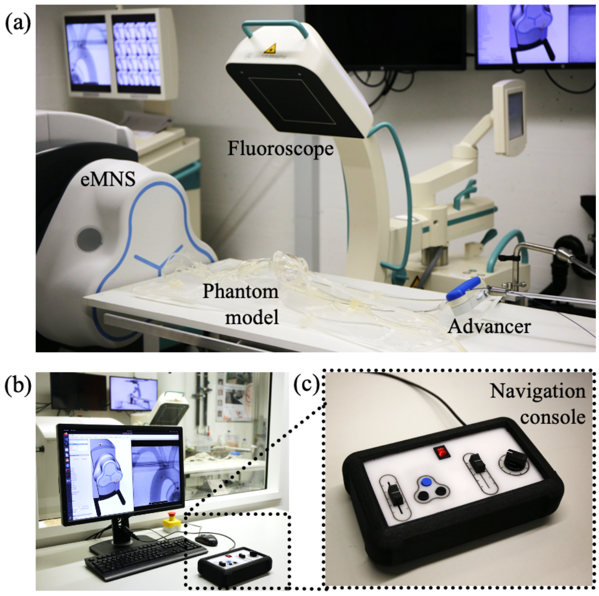

Fig 2 (a) Overview of the test setup, (b) user interface with monitor and x-ray image, (c) navigation console.

RESULTS

The realisation of the navigation console can be seen in Fig 2(c). We chose to map the in-plane azimuth angle of the magnetic field θ to a rotary knob and the off-plane inclination angle φ to a linear joystick. The dials on the navigation console are directional and reflect the current direction of the magnetic field at all times, as illustrated in Fig 3. To know the current state of the magnetic field, the operator can simply touch the dials on the console or look at them. In addition to the magnetic field inputs, the device has programable buttons and a linear joystick to control the catheter insertion speed. The interface was tested on a setup replicating the arrangement found in a clinical setting Fig 2(a). A 4 Fr magnetic catheter and 2 Fr guidewire were successfully navigated in the aortic arch Fig 3(a) and M1 cerebral arteries Fig 3(b) of the phantom model. The interface and control strategy were demonstrated to be effective in steering the magnetic instrument without the need of additional visual cues other than the already available x-ray image.

DISCUSSION

We introduced a new human machine interface that allows for magnetic catheter and guidewire steering. The interface does not depend on additional visual feedback other than what is already available in a standard operating room. The interface is intuitive and promises a shallow learning curve for new adopters, good catheter and guidewire control, improving patient safety, and simple integration in the operating room infrastructure.

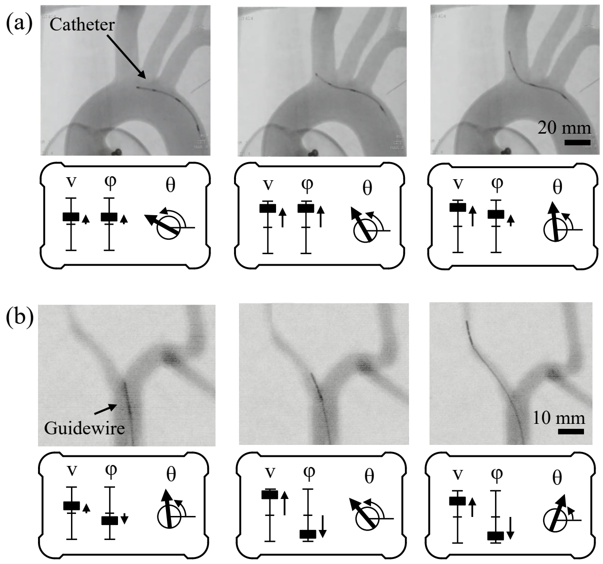

Fig 3 Navigating a 4 Fr catheter cross the aortic arch (a) and a 2 Fr guidewire in the M1 coronary arteries (b) in a silicone phantom model under no-flow conditions**.** In-plane steering is done with the θ-dial, off-plane adjustements with the φ-joystick, and insertion-retraction with the v-joystick.

ACKNOWLEDGEMENT

This work was supported by the Swiss National Science Foundation through grant number 200020B_185039, by the ITC-InnoHK funding, and by the ERC Advanced Grant 743217 Soft Micro Robotics (SOMBOT).

REFERENCES

[1] G. Britz, "An overview of neurovascular disease management," *Methodist DeBakey cardiovascular journal*, vol. 10, no. 4. Methodist DeBakey Heart & Vascular Center, pp. 212–213, Oct. 01, 2014. doi: 10.14797/mdcj-10-4-212.

[2] F. J. A. Mont`Alverne *et al.*, "Unfavorable vascular anatomy during endovascular treatment of stroke: Challenges and bailout strategies," *Journal of Stroke*, vol. 22, no. 2. Korean Stroke Society, pp. 185–202, 2020. doi: 10.5853/jos.2020.00227.

[3] T. Krings *et al.*, "Magnetic versus manual guidewire manipulation in neuroradiology: In vitro results," *Neuroradiology*, vol. 48, no. 6, pp. 394–401, Jun. 2006, doi: 10.1007/s00234-006-0082-3.