双胎間輸血症候群の手術ナビゲーションにおける内視鏡自己位置提示の設計

Workflow-centric design of 3D navigational cues for photocoagulation treatment in twin-to-twin transfusion syndrome

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Abstract: Twin-to-Twin Transfusion Syndrome (TTTS) due to imbalance circulation between twin fetuses results in high prenatal loss and risk of neurological impairment if not treated before birth. A fetoscope is used to guide laser photocoagulation of pathological vessels while ultrasonography guides instrument navigation. Mental registration of the two sources of guidance coupled with demanding minimally invasive constrains make the procedure challenging. Therefore, we propose navigational features that provide location awareness of the moving fetoscopic views. Its current view is graphically illuminated while dimming previous views to provide a dynamic visual cue of the endoscopic trail in the simultaneously mapped out placental vasculature on a 3D ultrasound model. A workflow-centric philosophy is adopted to minimize unnecessary burdens to the operating personnel using only fetoscopic and ultrasound imaging without external trackers. The navigational cues have been validated through visual inspections. Future study will include usability test of the navigational cues with expert subjects.

Key Words: Twin-to-Twin Transfusion Syndrome, Fetoscopic Procedures, Laser Photocoagulation

1. Background

Twin-to-Twin Transfusion Syndrome (TTTS) occurs in twins that share a common placenta suffering from imbalance in blood circulation due to communicating blood vessel that transfuse blood from one twin to another. This can lead to 90% prenatal loss or high risk of neurological impairment if left untreated before birth.

A common treatment is to perform laser photocoagulation on the pathological vessels that are responsible for the imbalance of blood circulation amongst twin fetuses. A fetoscope is used to guide laser photocoagulation on the pathological vessels. While fetoscopic procedures reduce the risk of medical complications, they provides limited field-of-view for navigation during placental imaging. Current practice uses ultrasound for navigation while the fetoscope inspects vessels on the placenta surface and guides laser treatment. This involves non intuitive mental registration of the two different sources of visualization in addition to the demanding minimally invasive constraint.

2. Objective

To address the challenges posed by the non intuitive perspective of existing navigation system and contribute to the development of computer aided surgery for fetoscopic procedures, this study proposes a workflow centric design of navigational features that provide surgeons with location awareness of the dynamic fetoscopic vision during photocoagulation treatment for TTTS.

3. Method

Our design approach adopts a workflow centric philosophy in that it aims to integrate data acquisition, which is required for navigational applications into the surgical procedures itself. Therefore, the navigational module is designed to blend in with the procedure without having to introduce external systems and additional tasks for the medical team. This is achieved through information fusion of ultrasonography and endoscopy for a range of navigational purposes including scene construction, tracking, texture mapping, and localization of current field of view with respect to the intraoperatively constructed map. This way of cue augmentation and mapping requires no tracking information of the freehand fetoscopic camera as it taps on the information of existing imaging modalities that is already in place for the procedure. Fig. 1 is a schematic illustration of the design concept that fuses the traditional use of multiple imaging displays into a single platform that provide navigational view with photorealistic scene.

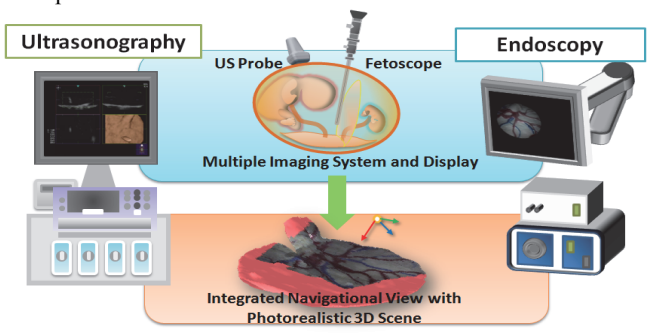

Fig. 1　Workflow-centric design concept

In this work, visual cues are proposed to facilitate location awareness in the vasculature map through highlighting of active field-of-view. The current view of the moving fetoscope is graphically illuminated while dimming previous views to

provide a dynamic visual cue of the endoscopic trail in the simultaneously mapped out placental vasculature on a 3D ultrasound model. This can be achieved by a straightforward linear combination of the intensity values of the overlapping imaged region. The common plane where the images are aligned on is subsequently projected to the ultrasound constructed 3D scene. Fig. 2 features the overview of the mapping framework.

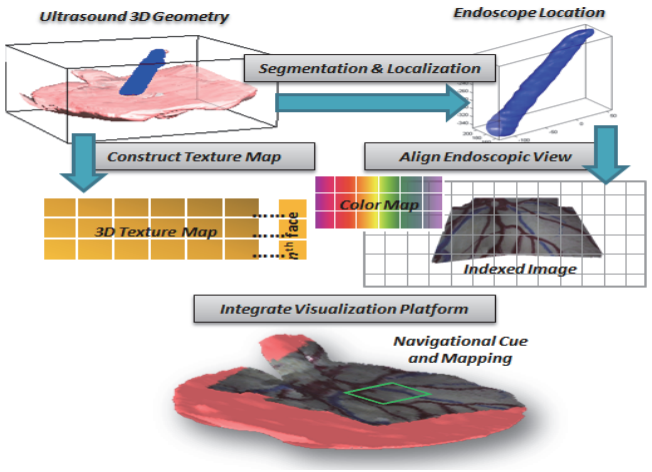

Fig. 2　Overview of the mapping framework

This untracked approach is discussed in a previous work [1] with greater details. In this paper, the relevant procedures will be explained concisely to ensure a self-contained discussion. Firstly, registration between the alignment plane and the scene geometry is done through a one-time ultrasound-based initialization, where the scene is segmented and endoscope localized. The spatial relation obtained from registration is used to map the photorealistic color map of the endoscopic views to the patches on the 3D scene to provide the mapping of the endoscopic trail and cue of the current view.

In addition, the proposed system also provides a wide mapped view of the placenta vasculature allowing surgeon to see regions that have been imaged without having to revisit them repetitively as in the case of narrow field-of-view fetoscopy hence addressing limitation in mental capacity for visualizing the vast placental vasculature with online updating of endoscopic view in the navigational map.

4. Results

The navigational cues have been validated through visual inspections. Fig 3. shows a 2D topological view with the graphically illuminated current view as a navigational cue.

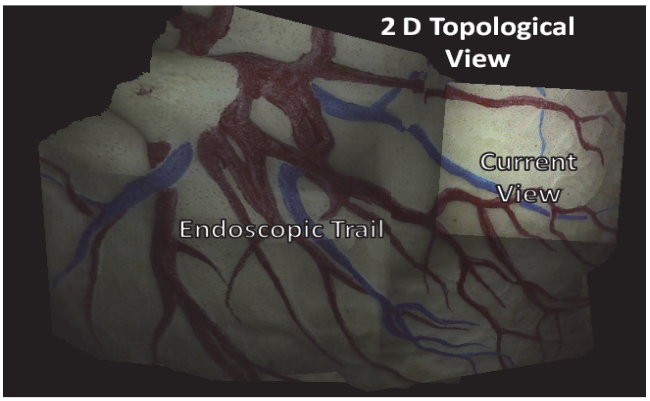

Fig. 3　Graphically illuminated current view

Based on observations, the moving trail of illuminated freehand endoscopic view provides useful visual cue on instantaneous location as well as a navigational map for manipulating the fetoscope during placental imaging. We are able to maintain the target registration error within 4 mm for an overlay of 1/3 the size of a placenta phantom, which has a round chorionic planar surface and about 18 cm in its longest dimension. Preliminary visual inspection on ex vivo monkey placenta also shows smooth mapping for more than 100 frames of image overlay.

5. Discussion

Visual observation of the navigational cues achieved through the workflow-centric design approach suggested that the vast vasculature on the placenta surface can be visualized in a single integrated navigational platform featuring the topological scene, updated endoscopic view, and the relative position of the latter with respect to the former all at the same time.

It is important to note, however, that the navigational cues do not directly enhance distinctiveness of the blood vessel. It provides only navigational guidance, which indirectly aid visualization of the vast vasculature. Nevertheless, because of its self-contained nature, the workflow-centric design approach allows incorporation of existing and developing technologies in visual enhancement of the blood vessels through contrast agents [2] or hyperspectral imaging [3] readily.

Future studies will include usability test on expert subjects to quantify the target registration error of the navigational cues.

6. Conclusion

In this work, we introduced navigational cues that enhance topological and location awareness for fetoscopic procedures where application of computer aided surgery technology has been lagging compared to other field of interventional medicine. By adopting a workflow-centric philosophy in the development of the navigational feature that minimizes procedural disruptions and unnecessary burdens to the operating personnel through a tracker-less approach, we hope to bridge the research gap between the developments of computer aided surgery and its applications for rare disease treatment like the TTTS.

Reference

(1) L. Yang, J. Wang, E. Kobayashi, *et al.*, "Image mapping of untracked free-hand endoscopic views to an ultrasound image-constructed 3D placenta model," *Int J Med Robot Comp (early access)*.

(2) K. Harada, M. Miwa, T. Fukuyo, *et al.*, "ICG fluorescence endoscope for visualization of the placental vascular network" Minim Invasive Ther Allied Tech, pp. 3-7, 2009.

(3) A. Kubota, L. Yang, J. Wang, *et al.*, "Contrast enhancement between vasculature and placenta using narrow band images for TTTS surgery," *28th International Congress and Exhibition of Computer Assisted Radiology and Surgery*, Fukoka, Japan, 2014.

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