A Virtual Fetal Environment for TTTS Applications

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INTRODUCTION

Twin-to-twin transfusion syndrome (TTTS) may occur during identical twin pregnancies when abnormal vascular anastomoses in the monochorionic placenta result in uneven blood flow between the fetuses. If not treated, the risk of perinatal mortality of one or both fetuses can exceed the 90% [1]. The most effective treatment to recover the blood flow balance is minimally invasive laser surgery in fetoscopy [2]. At the beginning of the surgical treatment, the surgeon identifies the inter-fetal membrane, which is used as a reference [3] to explore the placenta vascular network and identify vessels to be treated.

Limited field of view (FoV), poor visibility, high illumination variability, fetuses' movement, and limited maneuverability of the fetoscope make the membrane identification a challenging task. This results in increased surgery duration and risks of complications from the patients' side, as well as mental workload from the surgeons' side.

Recently, the Surgical Data Science (SDS) [4] community has focused more and more on developing mosaicking strategies to enhance surgeons' vision by extending the FoV. The literature approaches rely on instrument tracking or image analysis (i.e., no external hardware is required).

The work proposed by [5] integrates image processing with information on a fetoscope tip position, tracked by an electromagnetic tracker (EMT) to achieve drift-free mosaicking.

Among image analysis approaches, the first work proposed in [6] is based on the SIFT feature extractor for frame registration. Given the success of the deep learning techniques in vision tasks, researchers have exploited the potential of neural networks to extract features. In [7], a Siamese Network based on the VGG-16 backbone is proposed to extract vessel features combining region detection and stable image registration. In [8], the Lucas-Kanade algorithm was employed for frame registration of similar frames identified using bags of visual words based on VGG descriptors. The framework proposed in [9] uses a controlled data augmentation strategy and median outlier filter on estimated homography parameters for robust mosaicking. Most of the work in literature relies on a small dataset of fetoscopic images of the placenta acquired in-vivo (i.e., during the surgery), ex-vivo (i.e., using placentas removed after childbirth) or using phantoms.

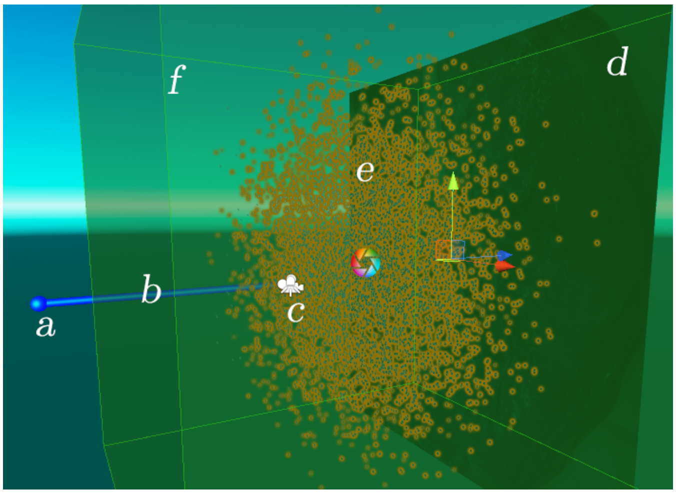

Figure 1: Overview of the scene elements in the virtual environment. a is the fulcrum of rotation of the instrument. On the tip of the sheath (b) the camera and a spot light (c) are attached. The ex-vivo placenta image is the texture of the image plane (d). The particle system (e) simulates the free-floating debris. All the elements are placed inside the amniotic volume f.

The training and evaluation of deep learning approaches require ground truth data. Ground truth could be obtained by employing a fetoscope tracker, which, however, may not always be available. To overcome this limitation, we propose a virtual environment for simulated placenta exploration, starting from ex-vivo images. We implement the virtual environment on a modern 3D game development platform, offering the possibility to simulate all possible scenarios of fetoscopic images (e.g., different light conditions, amniotic fluid turbidity, insertion point, camera pose, and particle density).

MATERIAL AND METHODS

In this preliminary study, our dataset is generated starting from three ex-vivo placenta images, acquired by clinicians right after TTTS surgery. The virtual environment can simulate both straight and 30 degrees fetoscope commonly used in TTTS surgery for the posterior and anterior placenta, respectively. An overview of the virtual scene is shown in Fig. 1. The chosen ex-vivo placenta image is projected on the image plane (d).

The fetoscope sheath (b) is modeled as a cylinder rotating with respect to a fulcrum (i.e., the insertion point, a). At the tip of the sheath, a virtual camera and a light spot (c) simulates the fetoscope's fibers-optics. Camera and light parameters are qualitatively tuned to produce images as similar as possible to intra-operative TTTS video frames acquired in the clinical practice (in this work, 10 TTTS intra-operative videos are available for visual comparison).

The virtual fetoscope is immersed in the amniotic volume (f),), modeled as a cube for simplicity. The cube is processed by a rendering pipeline to simulate the presence of the amniotic fluid. TTTS surgery is generally performed between the 16th and 25th weeks of pregnancy; in this period, the free-floating particulate is visible in the amniotic fluid. For this reason, we introduce a particle system (i.e., Unity module for the simulation of elementary particles, e) to simulate the particulate in the amniotic volume. Light intensity, amount of turbidity of the amniotic fluid, and particulate density can be changed during the simulation.

The virtual fetoscope can be moved to simulate different insertion points. After the operator has chosen the insertion point, the instrument can move freely or following a predefined trajectory through a keyboard. Other input controllers are allowed as well. During the free exploration, the user can start video capture and record the fetoscope's positions over time; it can be used later as a trajectory for further simulations or as an additional ground-truth datum. The user is provided with a small live reconstruction of the visited area at the bottom of the screen.

To experimentally evaluate the quality of the simulation, we decided to generate panorama using HomographyNet [10] trained on ex-vivo TTTS video frames generated with our environment. We chose this network given the promising results obtained in state of the art [9]. We computed the registration Root Mean Square Error (*RMSE*) [pixels] for each frame and compared to the ground-truth generated by the virtual environment to evaluate the panorama reconstruction quality.

RESULTS AND DISCUSSION

The virtual environment enables us to acquire nine videos. Each one was acquired using one of the three ex-vivo placenta images in our dataset, different fetoscope trajectories (i.e., free, circular and spiral) and different configurations of the virtual environment (i.e., different light intensity, turbidity of the amniotic fluid, density of free particulate) for 120 seconds (750 frames at 25 fps).

Preliminary results using the HomographyNet trained model on simulated data achieved an average *RMSE* of 4.18 pixels. An example of the reconstructed panorama is shown in Fig. 2.

Figure 2: Example panorama reconstruction on video generated from virtual environment using HomographyNet [10].

Future work will include an in-depth evaluation through clinician questionnaires. The virtual environment will be enriched implementing the following features: (i) optical distortion, (ii) placenta 3D models obtained from Magnetic Resonance Imaging (MRI) images, (iii) placenta texture generation using GAN networks with style-transfer, (iv) simulation of occlusions (e.g., fetuses) within the scene. The environment will be used to conduct further studies on more complex deep learning models for panorama reconstruction from in-vivo images.

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