EDITORIAL

Image-Guided Surgery and Its Future with the Artificial Intelligence

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1. What is Image-Guided Surgery?

Nowadays, the healthcare industry is very different from those in previous years, thanks to emerging advances in technology. Technology is increasingly playing a critical role in all aspects of the medical field, from diagnosis to treatment. Medical imaging technologies, which have made significant contributions to medicine over the last several decades, are one of the main areas of technological advancement. However, when it comes to surgical treatment, translation of the pre-operative images to the operation field is a challenging procedure for surgeons. The Image-Guided Surgery (IGS) system is one of the most widely acknowledged technologies in the area of surgery, from simple biopsy to complex surgeries [1]. IGS systems work in a similar way to the Global Positioning Satellites (GPS) that are used by automobiles. It will be impossible to imagine surgery without the use of IGS systems in the coming years, just as it is impossible to envision routing without a car or a mobile GPS today.

In IGS, surgical tools are tracked in a real-time procedure and displayed in the correct location and orientation on pre-operative images to directly guide the procedure. This technology enables the surgeon to precisely localize pathological tissue and relevant anatomical structures during a less invasive and safer real-time procedure. As a result, it has become a recognized standard of surgery in a variety of surgical specialties, including neurosurgery, spine, orthopedic, ears, nose, throat, and craniomaxillofacial [2, 3].

2. How IGS works?

Imaging, tracking, and registration are the three main stages of the IGS procedure. The first step is to obtain and upload pre-operative images of the patient to the IGS system. Different imaging modalities such as CT and MRI could be used in this part. There is no unique imaging modality that is exclusively used in IGS systems, so the selection of pre-operative images is dependent on a specific application. In the second stage, the navigation tool is tracked using a tracking system. Various tracking systems, including optical and electromagnetic tracking systems, are used to track surgical tools. Finally, the pre-operative image should be registered with the patient's position in a real-time process using the registration techniques. Registration is one of the most fundamental prerequisites and critical steps in IGS systems, which has a significant impact on system precision. As a result, one of the most challenging issues in IGS systems is to improve the accuracy of the registration process.

3. Future of IGS with the Artificial Intelligence

Technological advances in some existing areas, like Artificial Intelligence (AI), hold promises for IGS which could improve surgical planning and surgical navigation. In recent years, AI, particularly deep learning approaches, has attracted great attention for various applications in

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medical areas, such as image segmentation, image reconstruction, and image de-noising [4, 5].

One of the most important applications of deep learning is in computer-assisted diagnostic systems, including IGS systems to perform minimally invasive surgery, which has opened the following approaches [6]:

- Surgical image analysis, which includes classification and detection of surgical instruments, segmentation of surgical instruments, and segmentation of anatomical structures.
- Surgical task analysis, which could be classified into surgical phase recognition, gesture segmentation, trajectory segmentation, and surgery time prediction.

One of the main approaches in the future to make deep learning networks more specialized for image registration in specific applications is introducing registration priors to deep learning networks. Prior information related to the expected type of deformation, the spatial relationship between anatomical structures, and the topology and morphology of anatomical structures could be promising in this area. Also, we predict a greater emphasis on multi-modal registration by using deep learning techniques to go along with the increased availability of multi-modal datasets.

It seems that in the next 10 years, AI methods will create a revolution in IGS systems. Based on our understanding, there are two reasons for this claim. The first one is the high volume of medical data. However, many texts state that the volume of medical data is smaller than that in other fields, which could be a challenge for network training. But in fact, there are large amount of

- Surgical skill assessment.
- Automation of surgical tasks.
- Intelligent surgical training systems.

In addition to the above-mentioned issues which are proposed in different research, it seems that using AI in the image registration process could have dramatic implications for the future of IGS systems. However, the growth of AI in registration processes, especially point set registration, has not been as rapid as in other medical areas. One of the key reasons for this delayed growth seems to be the unknown nature of the transformation between preoperative and intraoperative situations, which leads us to use unsupervised learning models. Unsupervised methods as the most popular methods in image registration do not need any ground-truth transformation for data training and require only the moving and fixed images for training (Figure 1).

Medical data in various fields that have remained practically useless. The second one is that the problem of training with medical data can also be solved by developing a network architecture. On the other hand, processes such as image segmentation, which are performed manually by the physician in most medical processes, are very time-consuming; while deep learning approaches can enable network training based on physician knowledge as a gold standard in combination with conventional methods. In this way, physician knowledge is learned over time by networks.

In the end, we can expect that the entry and success of AI in processes such as segmentation of critical structures, including tumors and vessel structures, registration of images or point sets, surgical skill assessment, trajectory learning, and surgery time prediction, will revolutionize the future of navigation systems.

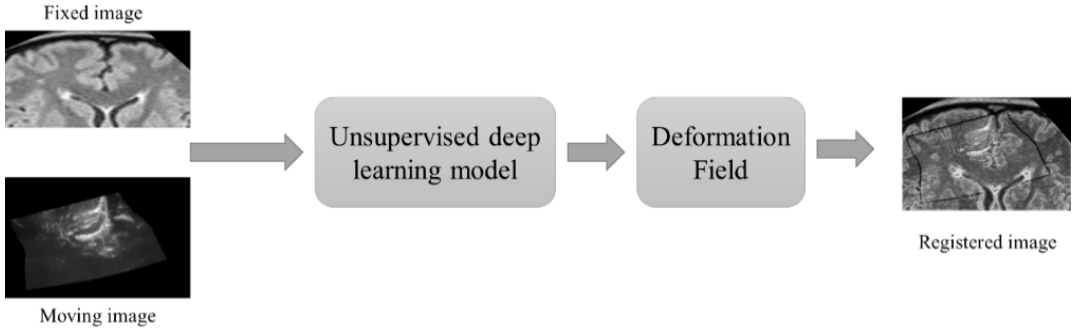

Figure 1. An example of the unsupervised framework used for brain MRI (fixed image) and ultrasound (moving) image registration

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