Marker-based Mixed-Reality System for Head Medical Treatment

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***Abstract*--Cumbersome equipment and complex algorithms are usually introduced in building an entire surgical system. These constraints will usually make the system less efficient, and not suitable in real surgical environments. In order to provide the physician a clear view of the locations of the lesions, an mixed reality approach to image-guided surgery is proposed.**

Our system integrates the medical imaging information obtained pre-operatively into the space of the real operation scene. The coordinates of medical images is integrated with a realistic dummy head model using the proposed Improved Alignment (IA) algorithm. In this way, we can help the physician, during the operation, to confirm the path of the operation and to verify the location of the lesion, thereby reducing the risk of the operation and improve the overall safety and accuracy.

INTRODUCTION

With the rapid development of computer and image processing technologies, the medical images, nowadays, play a very important part in assisting a physician's surgery. Before the operation, the doctors use various imaging instruments to obtain the patients' medical images such as CT, MRI and Ultrasound, which can be used to analyze the location of the lesion through these preoperative data [1]

However, it is very crucial to correctly align the medical images with the patient. The traditional registration method is the Iteration Closet Point (ICP) algorithm proposed by Kapoutsis et al. [2] in 1999, which uses a rigid conversion method to calculate the best transformation for converting a group of points to another group of points in a different coordinate system. In addition, Yang et al. [3] proposed the Go-ICP algorithm, which would effectively search for the best solution in the 3D motion space regardless of the initial location of the search.

The surgeons today still need to look up from time to time to the medical image monitor during the progress of the surgery. If the virtual and the real information can be displayed together, then the surgeon can focus on the medical images as well as the patients at the same time [4]. The new Mixed Reality technology is capable of achieving this requirement, which prompted our research.

METHOD

A. *3D Modeling using Medical Images*

In this study, a dummy model was used to simulate the head of a patient. First, a CT scan of the dummy model was processed to capture the region of interest, and a threshold value was used on the processed results, which are then stacked to obtain the 3D modeling data shown in Fig. 1.

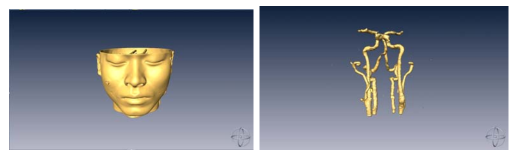

Fig 1: (a) Dummy Head Model; (b) Model of Vascular Tissue

B. *Surface Data Alignment*

Currently, the mostly widely used algorithm for surface alignment of three-dimensional objects is the Point Cloud Library-Iterative Closest Point (PCL-ICP) algorithm [5]. This algorithm is used to align two set of point cloud data, F(floating) and R(reference). The optimal coordinate transformation is computed iteratively using the least square method to obtain a rotational matrix R and a displacement matrix T, which are used to place the two sets of cloud points in the same reference coordinate system.

In this study, a stereo camera was used. Finding the corresponding coordinate points on the image plane captured by the left and right cameras to calculate the depth, the three-dimensional surface data can be constructed [6]. These correspondences were used to reconstruct the three-dimensional surface of the real object. In this study, an improved alignment (IA) algorithm was proposed to overcome the two problems of traditional ICP algorithm: first, a different choice of the initial position may cause the algorithm to be trapped into a local optimum solution; second, abnormal values may affect the result. Therefore, in order to solve these problems, the IA algorithm adds weights into the consideration in the process. The weights are calculated according to the distance between the corresponding points of the two cloud points sets, thus reducing the error caused by mismatching the points. In addition, during each iteration, a perturbation mechanism is added to help escape after falling into a local best solution.

The IA-ICP alignment algorithm flowchart can be divided into four major parts: Data Input, ICP Alignment, Stop Condition, and Perturbation Mechanism. The flowchart of this algorithm is shown in Fig. 2.

In each iteration, the traditional ICP method uses the value obtained from the object function as the evaluation value to be minimized. Therefore, the ICP algorithm may follow the

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direction of the descent to reach a local solution. In order to solve this type of problem, we propose using a perturbation mechanism to escape from being trapped into a local solution, and restart the search for the best solution.

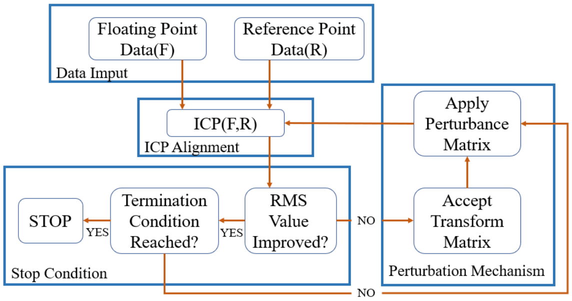

Fig 2: Flowchart of Improved Alignment (IA) Algorithm

C. Marker Detection

In conjunction with pre-operative spatial positioning, the dummy head model is placed beside a pre-set marker board in the operation to establish the coordinate relationship between the objects. When the marker board within the camera are detected, it will superimpose the virtual image on top of the dummy head model.

Our mixed reality system uses Vuforia's image-tracking SDK, which identified and tracks 2D planar images as well as feature points on the 3D images. Compared to ARToolkit, Vuforia will detect the marker image even if it is partially occluded. This research uses a self-made QR Code image as the marker.

D. Camera Position Estimation

In computer vision, the pinhole-imaging model, which also is also known as a pinhole camera model, is used. The rays of light refracted by an object passes through a pinhole camera and projected onto the film negative, which results in the formation of an opposite image of the object, which is upside-down. A given point in the three-dimensional space, (X,Y,Z) can be project to the camera's two-dimensional space image (x,y) though the camera's intrinsic parameter $(\alpha x, \alpha y, \mu o, \upsilon o)$, and extrinsic parameters, as described in the relationship in [7].

RESULTS

The hardware equipment used in this research include a desktop computer, Intel® Core™ i5-4460 running on Windows 10, and stereo cameras. For display, we used the MS HoloLens with a resolution of 1280x720, using smart glasses that allows users to interface using voice and gestures and interact. The software development was done with Unity.

When the Hololens camera detects the built-in feature points or QR code image next to the dummy head, the program will superimpose the medical image on the correct position in space and display the result to the user, as show in Fig. 3.

In addition, a cursor is added which can change the virtual objects' rotation angle and scale factor, and also facilitate the doctor to understand his current position in space.

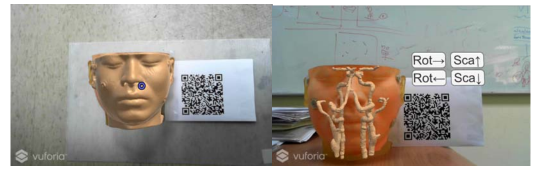
Fig 3: The results of the MR display

A Digitizer 3D spatial coordinate-measuring machine was used to take 5 reference points for the algorithms to compare against. As the number of source point clouds is larger than the number of target point clouds, the alignment will appear upside down or backwards and forwards. Therefore, for the PCL-ICP and CloudCompare-ICP, before performing initial alignment, the source point cloud must be compressed and adopted. The improved random sampling method makes the spatial distribution of point clouds more uniform. Unlike the PCL-ICP and ClouldCompare-ICP algorithms, our system which uses the Improved alignment (IA) algorithm and the Go-ICP algorithm both do not required a good initial position in order to get the best global solution. The error results in Table 1 shows that the improved alignment (IA) algorithm for the smallest error.

TABLE I: Error comparison

	IA-ICP error (mm)	PCL-ICP error (mm)	Go-ICP error (mm)	Cloudcompare-ICP error (mm)
Point 1	1.38	3.00	57.31	9.89
Point 2	1.30	2.14	32.09	8.30
Point 3	3.23	1.94	25.90	12.03
Point 4	4.12	2.81	38.26	9.72
Point 5	3.90	3.32	39.21	14.59

CONCLUSION

This study combined a mixed reality system into the medical display system, aligning the patient's pre-operative images with the world coordinate system, and presented in the result on a head-mounted display. The entire process does not need contact with the patient, decreases many inconveniences. The experimental results show that using the improved alignment (IA) algorithm works well in this method.

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