# A Novel Method and System for Stereotactic Surgical Procedures

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With the development of digital imaging technology, image-guided surgery (IGS) or surgical navigation has become one of the most rapidly developed techniques in minimally invasive surgery (MIS) in the past twenty years [1-11]. In conventional surgical navigation, the display used for the surgical navigation system is often placed in a non-sterile field away from the surgeon. This forces the surgeon to take extra steps to match guidance information on the display with the actual anatomy of the patient. This hand-eye coordination problem has been a big challenge. Recently, augmented reality (AR) technologies have been widely employed in IGS [12], e.g. head-mounted display (HMD) [13-14]. This system still has the problem of motion parallax lag and lacks multi-observers' field of vision. Another AR technology called image overlay [15-17] is emerging rapidly. With image overlay, computer generated anatomical models of lesion areas or the 3D structures reconstructed from medical images (computer tomography/magnetic resonance imaging, CT/MRI) are projected onto the patients' skin and registered with actual lesion areas precisely. Even this technology suffers from serious shortcomings. First, the direct projection onto the skin surface cannot produce a 3D image. Second, uneven skin surface leads to large distortions. Third, projected images do not match actual lesion areas. Additionally, these systems still suffer the problems of a lag for motion parallax, lack of natural view for multiple observers and visual fatigue [18]. The semi-transparent mirror technology has also been used in surgical navigation [19-21], but it is complex to operate.

We present here a novel AR technology based on passive polarized stereo projection and two semi-transparent mirrors for surgical navigation. The advantage of this technology is that the 3D images are created by computer reconstruction based on the 3D voxel data collected from the medical imaging equipment (multi-slice computed tomography scanner, MSCT) and the polarized stereo projection system. This provides geometrically accurate 3D spatial images and reproduces motion parallax with polarized eye glasses.

A set of accurate spatial image registration methods were developed for registration of 3D virtual images and the corresponding lesion areas. These methods are based on the co-ordinate transformation relationship of the world co-ordinate system, the CT image co-ordinate system, the view plane co-ordinate system of the vtkCamera (i.e. a virtual camera for 3D rendering) and the image plane co-ordinate system of projectors. Based on the above transformation relationship, the specific adjustment strategy includes 2 parts: size adjustment and posture adjustment of projected images through the PC control software.

The PC control software consists of three views: the main view, the left projection view and the right projection view. The 3D structure is reconstructed by surface rendering using the marching cubes algorithm.

From preliminary phantom registration experiments, we show that the average error of 4 selected surface markers (<3mm) meets the clinical requirement. The trapezium distortion of the projectors is 0.6 pixel distance. The differences of observer's height, inter-pupillary distance and motion have little effect on the registration accuracy. The human eye may have automatic focusing functions which increase the actual registration accuracy.

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## Abstract

- Image-guided surgery (IGS) or surgical navigation has become one of the most rapidly developed techniques in minimally invasive surgery (MIS) in the past 20 years.
- Conventional methods have the hand-eye coordination problem. Augmented reality (AR) technologies such as head-mounted display (HMD) has the problem of motion parallax lag and lacks multi-observers' field of vision. Another AR technology called image overlay cannot produce a 3D image and leads to large distortions.
- We demonstrate a novel AR technology based on **passive polarized stereo projection** and **two semi-transparent mirrors** for surgical navigation.
- The advantage of this technology is that the 3D images are created by computer reconstruction based on the 3D voxel data collected from the medical imaging equipment and the polarized stereo projection system which **provides geometrically accurate 3D spatial images and reproduces motion parallax with polarized eye glasses.**
- **A set of accurate spatial image registration methods** were developed for registration of 3D virtual images and the corresponding lesion areas with a preliminary phantom markers registration result of **less than 3 mm which meets the clinical requirement.**

## Passive Polarized Stereo Projection Technology

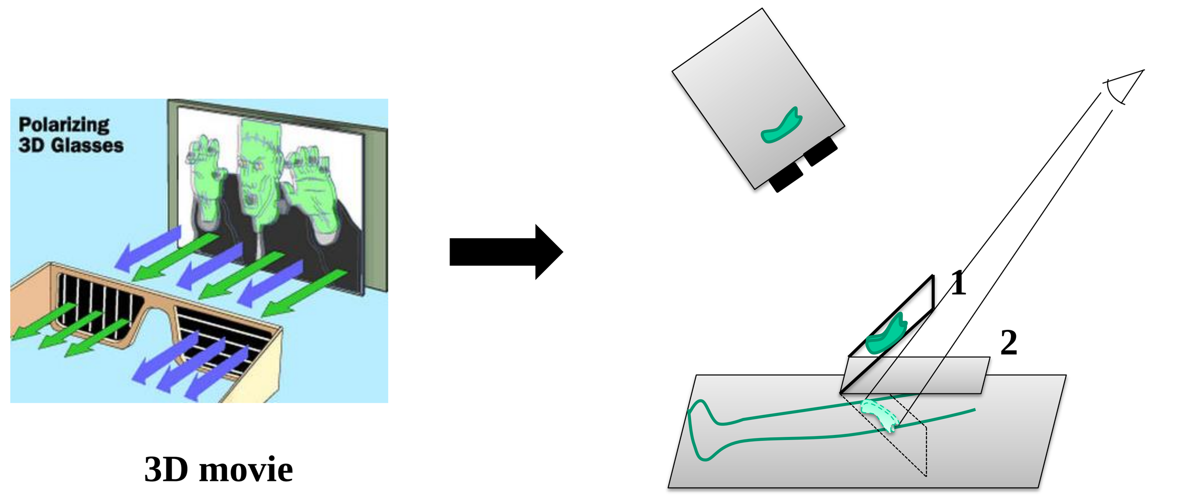



**Fig. 1 Passive Polarized Stereo Projector Theory.** Each front of projector lens is fixed with one linear polarized film with phase differences of 90 degrees to guarantee that the polarization state of two 2D projected images are mutually perpendicular to each other. Semi-transparent mirror 1 has a certain degree of fog and a layer of metal film thus implementing the function of diffuse reflection and permeability. Semi-transparent mirror 2 can achieve the function of specular reflection and permeability.

## System Configuration

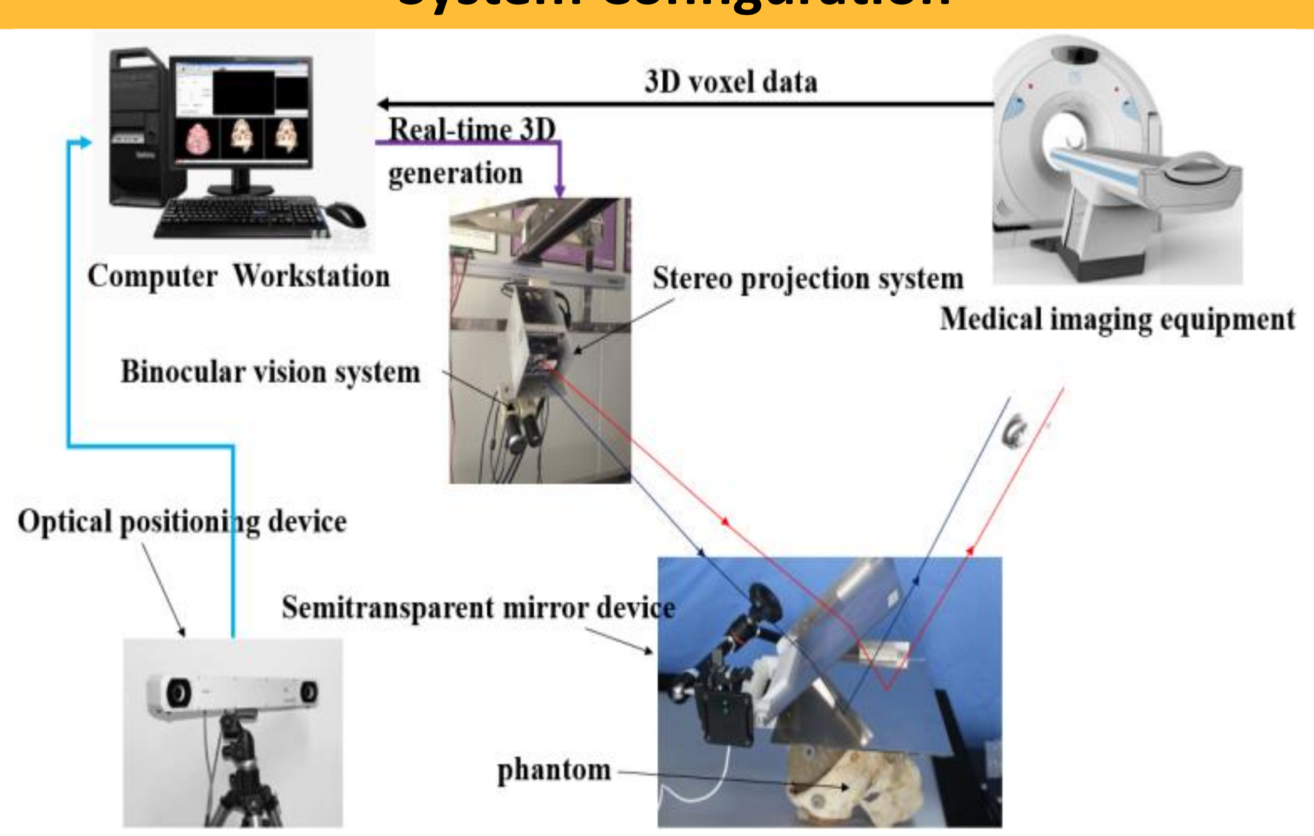



**Fig. 2 System configuration: instrumentation for stereotactic surgical system.** In order to achieve the fusion of computer-generated 3D images and real objects, that is a kind of "perspective " effect, we developed a novel system for stereotactic surgical procedures.

## Spatial Image Registration

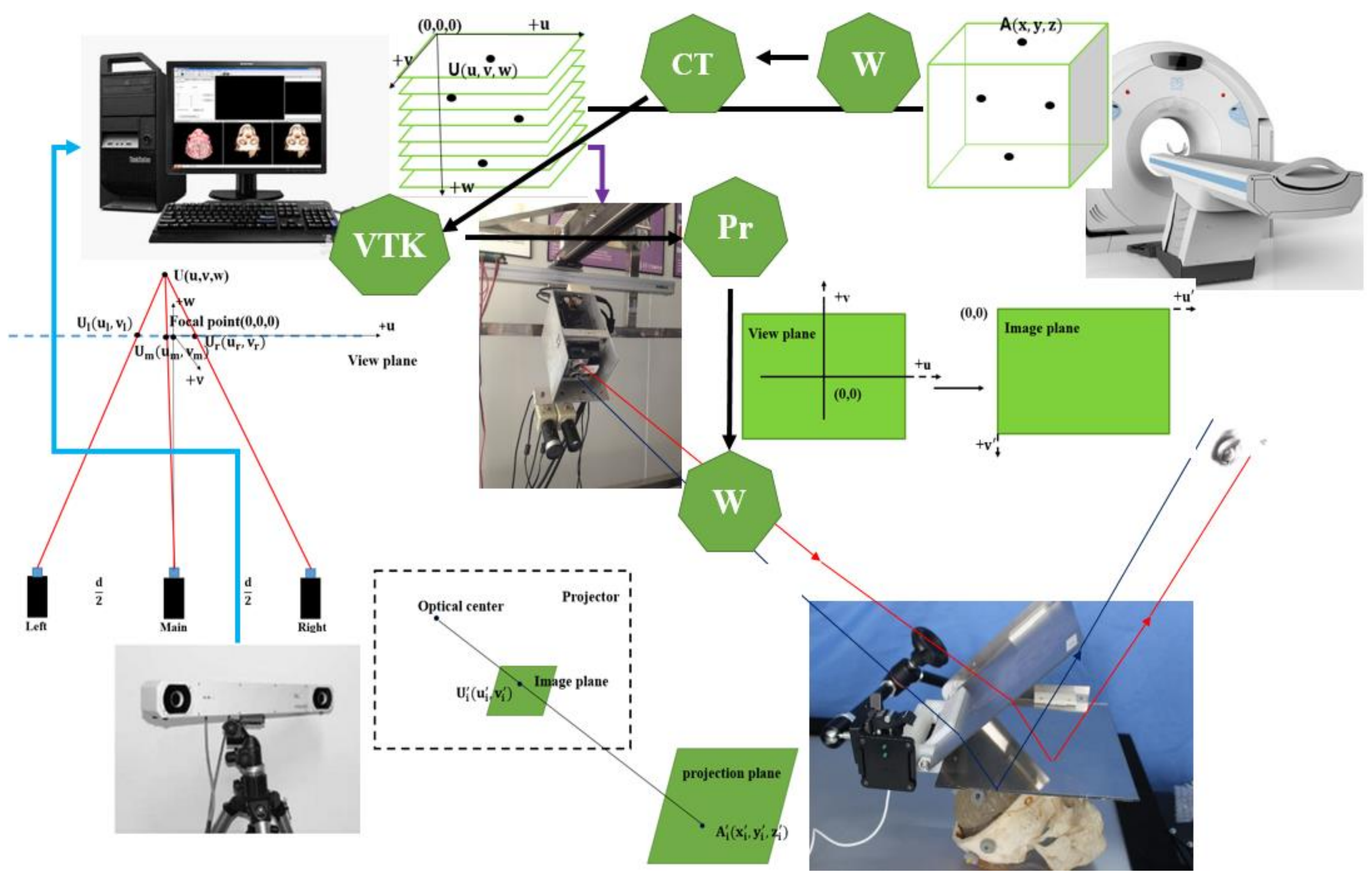



**Fig. 3 Principle of spatial image registration methods.** These methods are based on the co-ordinate transformation relationship between the coordinate system. W: the world coordinate system, CT: computer tomography image coordinate system, VTK: the view plane coordinate system of the visualization toolkit, Pr: the image plane coordinate system of projectors.

## Posture Adjustment Strategy of Projected Images

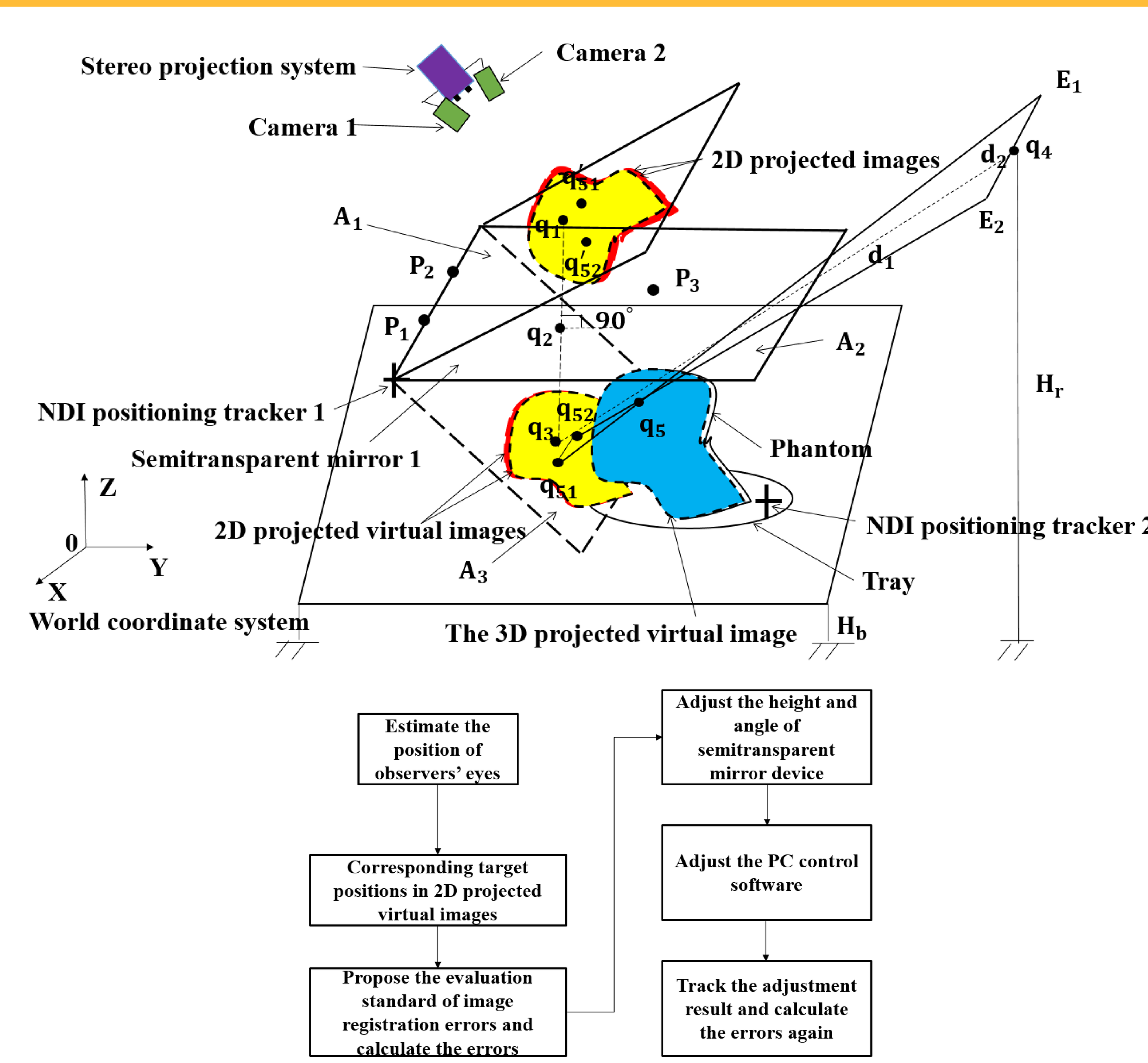



**Fig. 4 Framework of posture adjustment strategy of projected images.** The posture adjustment of projected images includes two parts: 1) coarse adjustment of hardware component; 2) software adjustment of physical spatial coordinates of markers in the 2D projected images ($q''_{51}$ and $q''_{52}$) to approach the target positions of corresponding markers ($q'_{51}$ and $q'_{52}$) through changing the corresponding positions of the points in the view plane coordinate system based on the above transformation relationship and calculate the image registration errors to evaluate the posture adjustment effect.

## PC Control Software

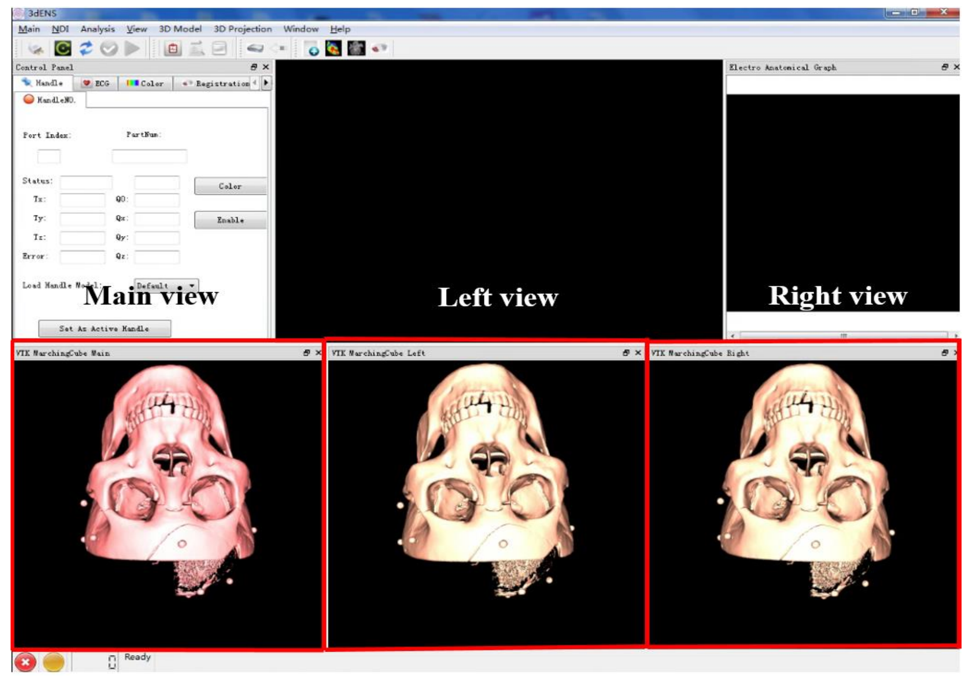
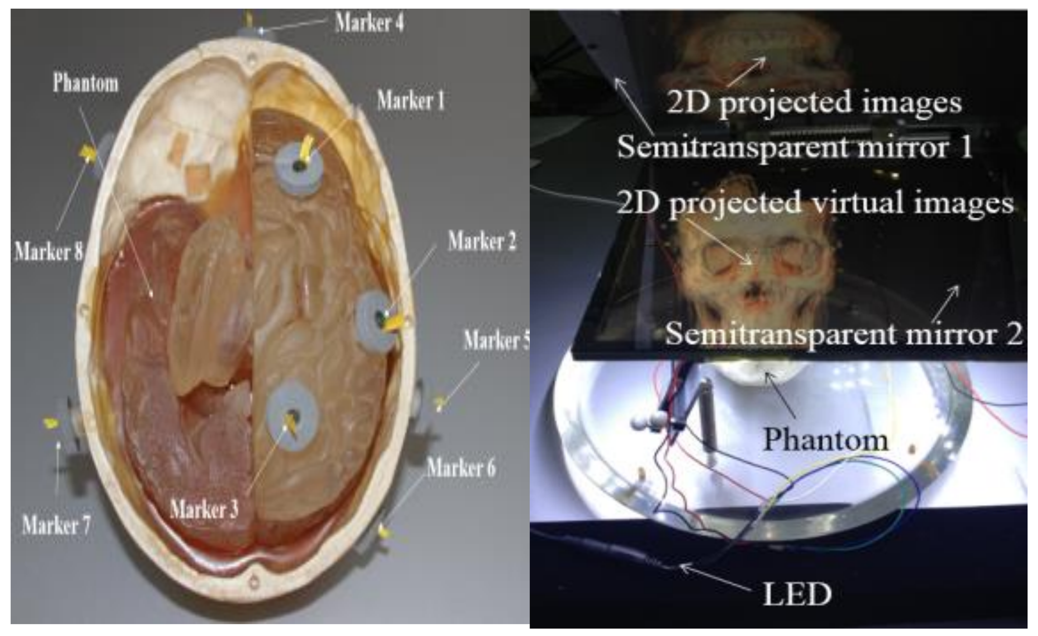



**Fig. 5 PC control software interface.** The PC control software consists of three views: the main view, the left projection view and the right projection view. Three 3D structures are reconstructed using surface rendering with marching cubes algorithm. Two 3D structures in the left projection view and the right projection view have certain angles based on the parallax of the two eyes.

## Preliminary Phantom Registration Result




| Observers | Markers | Physical positions of markers in the phantom(mm) | Target positions of markers in 2D projected image 1(mm) | Target positions of markers in 2D projected image 2(mm) | Physical positions of markers in 2D projected image 1(mm) | Physical positions of markers in 2D projected image 2(mm) | Registration error(mm) |
|---|---|---|---|---|---|---|---|
| **1(1650mm)** | 2 | (-67.5,113.0,-1708.1) | (-146.0 109.2-1712.4) | (-145.4, 107.5,-1706.9) | (-147.0, 110.2,-1712.9) | (-144.5, 108.6,-1708.1) | 1.65 |
| | 5 | (-17.5,124.8,-1687.9) | (-171.5, 140.9,-1678.5) | (-173.1, 141.3,-1677.6) | (-172.4 141.5,-1679.8) | (-174.4, 142.5,-1678.8) | 1.90 |
| | 7 | (-29.0,168.9,-1827.6) | (-196.0, 165.3,-1819.9) | (-199.5, 168.5,-1815.1) | (-197.8, 166.2,-1821.1) | (-200.9, 170.8,-1816.0) | 2.56 |
| | 8 | (-77.2,185.3,-1810.5) | (-184.0, 149.1,-1816.1) | (-178.4, 145.0,-1808.9) | (-184.0, 150.8,-1817.7) | (-179.6, 145.7,-1810.9) | 2.36 |
| **2(1750mm)** | 2 | (-67.5,113.0,-1708.1) | (-146.4, 109.1,-1711.5) | (-144.0, 107.6,-1709.5) | (-147.0, 110.2,-1712.9) | (-144.5, 108.6,-1708.1) | 1.86 |
| | 5 | (-17.5,124.8,-1687.9) | (-170.3, 139.2,-1677.3) | (-173.8 141.7,-1677.1) | (-172.4 141.5,-1679.8) | (-174.4, 142.5,-1678.8) | 3.16 |
| | 7 | (-29.0,168.9,-1827.6) | (-196.3, 165.8,-1819.7) | (-198.8, 169.3,-1815.1) | (-197.8 166. 2,-1821.1) | (-200.9, 170.8,-1816.0) | 2.39 |
| | 8 | (-77.2,185.3,-1810.5) | (-183.0, 149.2,-1815.9) | (-178.0, 144.5,-1809.1) | (-184.0, 150.8,-1817.7) | (-179.6, 145.7,-1810.9) | 2.64 |

**Fig. 6 Phantom registration result.** There exist 8 surface markers in the phantom. Due to the viewing angle, the actual markers can be observed are 4 ones, namely point mark 2, 5, 7, 8 thus registration errors analysis is based on these reference markers. The two observers' height selected are 1650mm and 1750mm. The interpupillary distance is selected as 65mm.

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