1. Introduction
An accurate and reliable system for instrument tracking constitutes a fundamental tool for assisted and virtual surgery. One of the most diffused systems of this kind is Polaris™ by NorthernDigital™, where two or more cameras survey set of passive markers placed on the surgical instrument. However, this as many other motion capture systems, cannot cope with partial occlusions of the markers, which often occur often when two instruments are used at the same time. Moreover, they need eccentric supports for markers to identify the axial rotations, making such system quite obtrusive.
We present here a system that solves both problems. It was implemented for a virtual eye surgery simulator, which can be profitably used for the training of young eye surgeons.

2. Methods
Three spherical, white markers (1mm Φ) are attached to the tips of two eye surgical instruments (Fig. a). The tips move inside a very small working volume of 20x20x20 mm, surveyed by four firewire Basler A601f cameras (B&W, 480x480 pixel @8bpp) equipped with proper macro lens and illuminators. The system is enclosed into a box of 400x400x300 mm and a plastic mask of a human face is positioned above it (Fig. b). Two small holes in correspondence of one of the two eyes allow the tips to be inserted by the surgeon during the simulation procedure (Fig. c). Cameras are calibrated using classical bundle-adjustment, with tools developed ad-hoc.

A dedicated, real time algorithm is used to accurately identify the centroid of the markers even in presence of partial occlusion. To this aim, each image is first binarized and each connected component is associated to one of the markers visible in the scene. The exact position of the centroid of the marker is computed maximizing an ad hoc defined likelihood function that explicitly takes into account that some of the pixels inside the marker area cannot be visible [1]. The markers are tracked in 3D space combining geometrical multi-camera constraints and the geometrical model of the instruments, acquired at calibration time. From the 3D position of the markers, five of the six degrees of freedom of each instrument are computed through simple geometrical considerations.

The sixth degree of freedom of each instrument (the rotation around its axis), is determined from a black stripe painted over the surface of the head marker (Fig. a). The stripe is identified over each camera and back-projected over the marker surface. From this 3D pose of the stripe, the axial orientation of the instrument is recovered. Resorting to more views improves the overall accuracy, which is higher than 0.1mm in instruments position and than 1° in orientation (1.5° for the axial orientation). All processing allows a sustained 30Hz video acquisition and processing on a general purpose host PC.

3. Results and conclusion
White markers have been used here to identify the instruments: as the box containing the system is closed and the light is controlled, this allows the white markers to stand out clearly. In the operating room, the markers are usually retro-reflective, but the method can be applied as well. Young surgeons have extensively used it to practise on basic eye surgery movement. Different virtual instruments (Fig. d) were placed at surgeon’s disposal. All surgeons reported a smooth and realistic representation of the instruments motion and did improve over time.

4. References