

Sight-based Magnification System for Surgical Applications

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Abstract. This work presents the development of an augmented reality magnification system implemented in a head-mounted display for surgical applications. The system provides a magnified view with a novel control based on tracked sight orientation. The system was evaluated by measuring the completion time of a suturing task performed by surgeons. The magnifying approach implemented provided global context of the operating field. The sight-based activation was widely accepted by surgeons as a useful functionality to control viewing modalities.

1 Introduction

Augmented reality (AR) is defined as a technology in which the user's view of the real world is enhanced or augmented with additional information generated by a computer [1]. In the medical domain, AR technology has been used to assist surgical procedures, including the development of medical virtual tools [2].

Medical AR systems based on the use of surgical microscopes have been developed and tested. Birkfellner et al. [3] introduced an adapted commercial head-mounted operating microscope for stereoscopic augmented reality visualization. In a more recent work, Garcia et al. [4] developed an AR system to align preoperative tomographic images into a surgical microscope with a rigidly mounted mini-tracking system to track movements of surgical tools and the patient.

Despite high quality of real optics in head-mounted microscope AR systems, the continuous magnified view aligned to the eyes' sight, disables the surgeon to visualize other areas in the operating room (OR) with normal vision. In addition, the linear magnification occludes visual information below the magnified space, restricting the observer to perceive complete information surrounding the operating field. In order to overcome these limitations, we propose a head-mounted magnification system with sight-based activation.

2 Material and Methods

2.1 Hardware Setup

The hardware consists of a video-see through head-mounted display (HMD) with two color cameras attached to the HMD (Fig. 1), a pointer tool, and two infrared based tracking systems to have high-precision tracking.

The internal tracking system, termed RAMP [5], consist of a single infrared camera, mounted on the HMD, for tracking a reference frame to provide the HMD pose with high rotational accuracy.

The external tracking system (A.R.T. GmbH) consists of a set of four infrared cameras attached to the ceiling that covers a working area of approximated 2.5m^3 . The target's tracking accuracy is around 0.35mm . Since this is not a single, but multiple camera system, it requires an arrangement with a minimum of four fiducial markers for obtaining the six degrees of freedom (DOF) position of the target. This system is used for tracking the pointer tool's tip, the reference frame and the HMD pose in case that the reference frame target is out of scope of the RAMP system's infrared camera.

2.2 Sight-based Activation

Our system provides an intuitive control to activate and deactivate the magnified view by means of tracking the HMD's sight. When the user focuses on the operating field the magnification will be turned on. Focusing outside this area it will be turned off, allowing the surgeon the freedom to perform other tasks with normal vision, such as grabbing surgical instruments, monitoring medical devices in the OR, or interacting visually with medical partners.

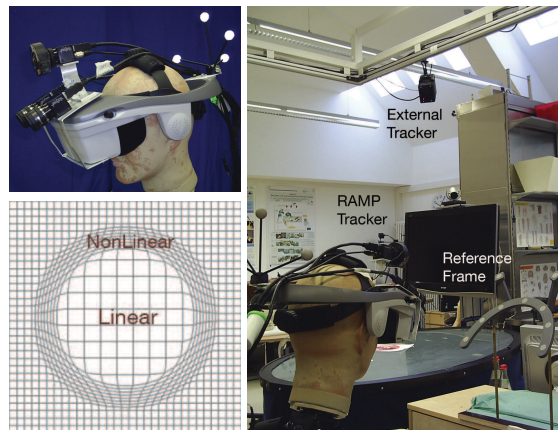


Fig. 1. Head-mounted magnification system (top-left). Hybrid magnification approach (bottom-left). Tracking system setup (right).

In order to establish when the user is focusing on the operative field, a vector of sight and its distance from the working area are determined as follows. First, the position of the pointer’s tip is saved to define location of operating field. Then, the distance d between the saved location and left camera of the HMD is calculated. Then the angle α between the camera’s sight vector s and the normalized distance vector \hat{d} is computed based on the dot product of two vectors, i.e., $\alpha = \cos^{-1}(\hat{d} \cdot s)$. Experimentally, we defined that if $d < 50$ cm and $\alpha < 15^\circ$, then the magnification is activated. Camera location and orientation were obtained from the translation vector and rotation matrix contained in the following transformation:

$$\text{ext}T_{\text{cam}} = \text{ext}T_{\text{ref}} \cdot (\text{ramp}T_{\text{ref}})^{-1} \cdot (\text{cam}T_{\text{ramp}})^{-1} \quad (1)$$

where $\text{ext}T_{\text{cam}}$ denotes transformation from external tracking system to HMD’s left camera, $\text{ext}T_{\text{ref}}$ is from external tracking system to reference frame, $\text{ramp}T_{\text{ref}}$ is from RAMP system to reference frame and $\text{cam}T_{\text{ramp}}$ is from left camera to RAMP system.

2.3 Hybrid Magnification Approach

Different methods for implementing general non-linear magnification transformations are presented by Keahey and Robertson [6]. We have adapted and applied these concepts into an HMD for AR.

The hybrid magnification approach implemented consists of a radial linear magnification surrounded by a radial non-linear magnification with constrained domain (Fig. 1). The non-linear magnification transforms each point in the domain as follows: given a center point of magnification $C = (C_x, C_y)$ and a point to transform $P = (P_x, P_y)$, let $\hat{P} = P - C$. Find the radius component of the polar coordinates of \hat{P} so that $r = \sqrt{\hat{P}_x^2 + \hat{P}_y^2}$. The new coordinates are then $C + \frac{h(r)}{r}\hat{P}$, where $h(r) = \tanh(r)$.

The linear magnification presents a uniform level of magnification across the domain. In a constrained magnification, transformations are performed inside a sub-area of the domain; all points outside the domain remain untransformed. This preserves global context.

3 Results

Five surgeons from our clinical partner, experts on microsurgery, were volunteers for performing a suturing procedure assisted by our system (Fig. 3). The experiment consisted on practicing two single knots on a suturing module for testing two different magnification modes ($2\times$ factor): hybrid and linear (Fig. 2).

First, the artificial wound location is determined, by means of the tracked pointer, and saved in the system. Then, the pointer is removed and the surgeon starts suturing with a randomly selected mode. This is repeated with the

Table 1. Suturing task completion time. Linear & hybrid mode were set to 3 & 2 and 2 & 3 for first and second trial, respectively. All measures are given in [ms].

	All trials		First trial		Second trial	
	Linear	Hybrid	Linear	Hybrid	Linear	Hybrid
Average	161.40	157.40	171.67	203.00	146.00	127.00
Standard deviation	24.17	43.31	26.31	9.90	12.73	15.39

remaining mode on a second suturing module. The results of experiments are presented in Tab. 1.

Due to the learning curve intrinsic in the experiments' repetition and adaptation to the AR system, we were expecting that the time for performing the second trial would be faster than the first one. Thus, we consider relevant to analyze first and second trials independently. Three surgeons were evaluated first with linear mode and the remaining two with hybrid mode. In contrast, the second trial had two surgeons with linear and three with hybrid.

It is very interesting to notice from these results that, during the first contact with the AR system (first trial), the surgeon performed the suturing procedure faster with linear mode (magnification similar to the medical loupe, with which the surgeon is completely familiarized). On the other hand, after the user was

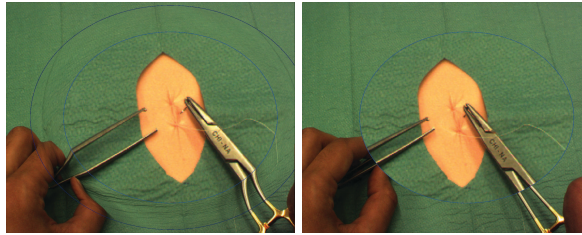


Fig. 2. Magnification modes displayed into the HMD: hybrid (left) and linear (right).



Fig. 3. Surgeon assisted by: the magnification system (left) and a surgical loupe attached to the glasses (right).

adapted to the AR system (second trial), it took less time for suturing with hybrid mode.

4 Discussion

A magnification system with sight-based activation was developed for surgical applications. The sight-based activation control supplied a novel functionality. The magnification approach provides continuity between magnified and non-magnified areas, prevents occlusions and provides a global context of the operating scene.

By wearing a surgical loupe (Fig. 3), the user can also switch between regular and magnified views by moving the eyes; however, the user will get a semi-obstructed and restricted view. The magnification system allows to automatically recovering a complete field of view. Moreover, an AR system could provide additional features taking advantages of digital manipulation which optical devices could never offer.

As advances in hardware will provide the scientific community with higher resolution and lighter HMDs, the novel software solution, such as the one presented here, pave the path towards integration of AR into medical applications.

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