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Eye-Controlled Microscope for Surgical Applications

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When a surgeon operates with a microscope, several controls of this instrument such as the positioning, the zoom or the focus have to be frequently modified. Since the surgeon's hands are generally occupied with the manipulation of surgical instruments, he may for example have recourse to some external aid, such as an assistant, but this is expensive, and it involves not only a certain response time but also a relatively major risk of errors. Similarly, to modify the adjustments, the surgeon can use pedal-actuated commands, but this offers limited command possibilities and entails an increased risk of confusion in emergencies. Vocal command with automatic speech recognition could have been an advantageous solution, except that at the moment it is more oriented to all-or-nothing commands than to continuous commands. Moreover, in situations of nervous tension, the reliability of vocal recognition is altered because of modifications in the tone of voice or changes in the ambient sound level.

The idea of using the ocular movements of an observer for the control of specific actions is not new. A system commanding weapons orientation with the eye movements was described by Abbey [1] in 1968. Other applications have been proposed for the communication of handicapped people and for the replacement of computer keyboards.

However, using ocular movements for the control of a microscope is not a simple designation problem. For example, any action on the microscope

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position has a direct influence on the image seen by the surgeon. This creates a feedback loop which may interfere with the feedback loops already present within the sensorimotor visual system.

Therefore, two major problems have to be solved: the first is the integration of the eye movement sensor within the microscope, and second is the conception of control algorithms which are compatible with the normal functions of the visual system.

The Eye Movement Sensor

A suitable technique for measuring eye movements should be non-invasive. Therefore, it should be based on some optical principle. It should differentiate rotations of the eye from translations of the head. The technique which has been implemented on the microscope is based on the Hirschberg [2] principle. It measures the eye orientation from the relative position of the pupil and the corneal reflex. These two images move simultaneously when there is a translation movement of the head and relatively to each other when the eye rotates.

The optical setup is shown in figure 1. The near infrared radiation emitted at 880 nm by a light-emitting diode (5) illuminates the eye of the surgeon after reflection on a hot mirror (2). Part of the incident light beam is reflected by the front of the cornea and produces the so-called corneal reflection. The remaining light enters the surgeon's eye, is refracted back from the retina and back lights the pupil, producing a 'bright pupil' effect. The image of the eye is formed by a lens (6) on a compact CCD image sensor (3) after reflection on the hot mirror (2) and the beam splitter (4).

With the present prototype, the space required by the eye movement sensor between the eye and the microscope ocular has been reduced to 12 mm. This setup does not interfere with the normal vision of the surgeon, even with wide field oculars. The only limitation is with eye glasses which produce an undesirable reflection of the near infrared light. This reflection can be avoided by tilting the correction glass or by inserting the optical correction between the ocular and the hot mirror.

The Control Algorithms

As mentioned previously, the control of the microscope with eye movements introduces a second feedback loop superimposed on the retroactions

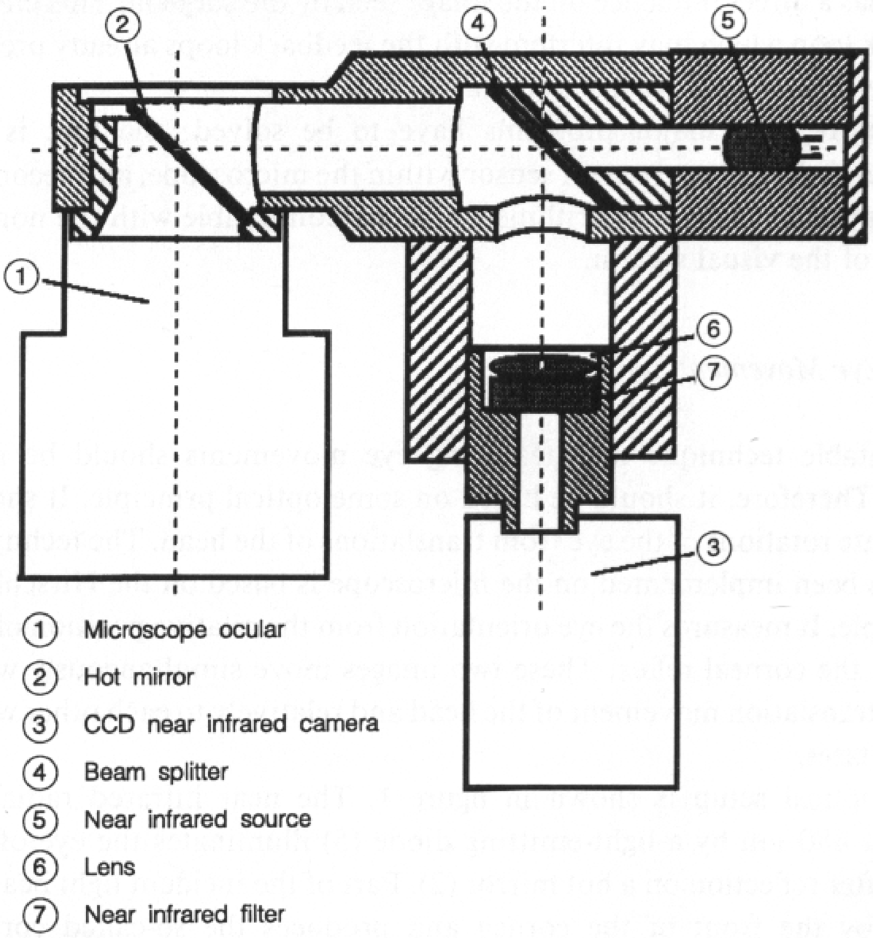

Fig. 1. The eye movement sensor.

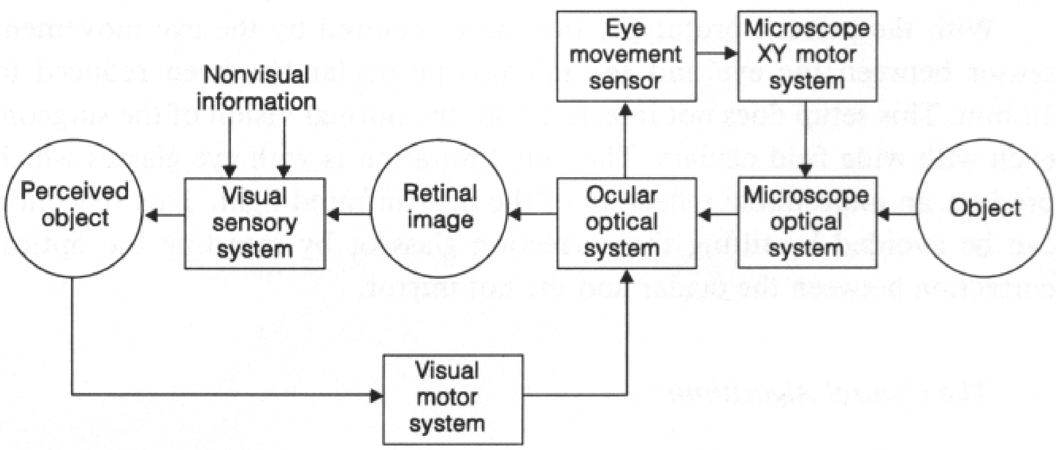

Fig. 2. Schematic of the two feedback loops involved in the eye-controlled microscope.

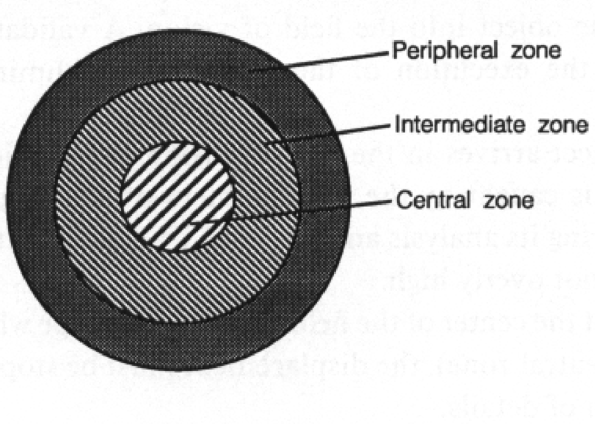

Fig. 3. Command zones within the microscope's field of vision.

already existing within the visual system. It is therefore necessary to take into account these existing retroactions to conceive the algorithms controlling the movements of the microscope.

The existing retroactions are mainly due to the fact that a steady eye is capable of resolving fine spatial details only within a small domain corresponding to the fovea. Eye movements increase the visually perceivable domain by allowing a selection of the object whose image is formed over the retina. These movements are controlled by complex neurophysiological mechanisms which contribute to the construction within the brain of a representation (perceived object) of the outside world (object).

These mechanisms involve an information feedback loop (fig. 2) including 3 major programs: (1) the fixation program maintains the retinal image of a steady object in coincidence with the fovea; (2) the pursuit program provides a tracking by the fovea of an object in motion; (3) the saccade program triggers a fast eye movement which brings into coincidence with the fovea the retinal image of an object detected in the periphery.

The eye movement controlled microscope introduces a second feedback loop (eye optical system → eye movement sensor → microscope motor system → microscope optical system) which must be compatible with this existing neurophysiological feedback (ocular optical system → retinal image → visual sensory system → perceived object → visual motor system).

This has been achieved by dividing the field of vision within the microscope into three different zones (fig. 3).

When the surgeon's sight is detected outside the field of vision of the microscope (peripheral zone), this is interpreted as designating an object of interest in peripheral vision. In this case, the microscope is displaced at maximum speed, to move the object into the field of vision. A validation time is introduced prior to the execution of the command to eliminate possible errors.

When the designated object arrives in the field of vision of the microscope (intermediate zone) it is caught by the visual system of the surgeon which is then capable of assuring its analysis and tracking, on condition that the speed of displacement is not overly high.

When the object arrives at the center of the field of the microscope where vision is most comfortable (central zone), the displacement must be stopped to enable a precise perception of details.

Conclusion

This new instrument has been tested in the operating room by Dr. Sourdille and Dr. Ducourneau. Both surgeons have been able to control the instrument and to perform surgery with it after a few minutes.

The setup of the instrument was adapted to each surgeon and each type of surgery by adjusting the parameters defining the extent of each control zone, the validation time in the peripheral zone, and the speed of displacement in the intermediate zone.

The experimentation demonstrated the value of the instrument particularly when high magnification is needed together with frequent displacements of the microscope.

References

1 Abbey: Guide weapons of aircraft. US patent 3,375,375. 1968.
2 Hirschberg J: Über die Messung des Schielgrades und die Dosierung der Schieloperation. Centrabl Prakt Augenheilkd 1885;8:325.

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