

A stereo-fiberscope with a magnetic interlens bridge for laryngeal observation

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A stereoscopic method of observation of the larynx and the pharynx during speech utterances has been devised, making use of fiber-optic cables and a magnetic bridge. The cables are inserted via the subject's nostrils. The bridge makes the two objective lenses at the tips of the cables abut within the pharynx near the uvula, and the two images viewed through the separate lenses at the prescribed mutual distance are recorded on each frame of a 16-mm film side by side for computer processing of the three-dimensional data.

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The use of a specially designed fiberscope for insertion through the nasal passage of a subject during speech utterance (Sawashima and Hirose, 1968) has contributed significantly to our understanding of laryngeal gestures with respect to both segmental and suprasegmental phonetic control. One difficulty, however, was the lack of quantitative information regarding the actual distance between the objective lens, the tip of the optical cable which is located within the subject's pharynx underneath the velopharyngeal port, and the glottis or related structures under observation. The vertical position of the larynx is known to change considerably during speech gestures, and these movements have been one of the foci of interest in phonetic studies and modeling of the vocal cord mechanism (Fujimura, 1977a; Stevens, 1977; Ohala, 1977; Maeda, 1976). Also, unless we have an estimate of the distance between the object and the objective lens, we cannot assess dimensional measures such as glottal width.¹

Some preliminary studies have been conducted concerning the possibility of using a stereo-fiberscope for such purposes (Sawashima and Miyazaki, 1974; Niimi and Fujimura, 1976). In the past, however, the use of such a stereoscopic observation technique was extremely difficult because it required the painful process of pulling the tips of the two fiberglass bundles out from the pharynx (after their insertion through the nostrils) to the outside of the mouth. This process was necessary in order to fix the two lenses relative to each other by means of a metal connector. The combined cables also had to be pulled out of the mouth for disassembling after the experiment. Recently, to solve this problem, a special magnetic bridge was devised by the present authors (Fujimura, 1977b). A preliminary data collection session has been conducted at Haskins Laboratories, and the device has been found satisfactorily effective and simple to use.

A stereo-fiberscope, manufactured by Olympus Corporation according to our specifications, was used. It consists of two independent fiberoptic cables each with an objective lens housed in its tip, a joint structure which accommodates an eyepiece, and to which the two image cables and an illumination light guide are connected. The two image fields, as viewed through the two objective lenses, are recorded side by side on each frame of photographic film (see Fig. 1). A thin tube of ferromagnetic material with a longitudinal split was fitted as a sheath around the tip of each fiberoptic cable for this experiment (see Fig. 2). A special concave composite magnet fits between these tubes and serves as a bridge, fixing the two objective lenses at the specified relative positions. The interlens distance is adjustable by selecting an appropriate dimensions of the bridge.

The magnetic piece consists basically of two magnets of opposite transverse directions of polarization. This magnetic structure has been found particularly suitable

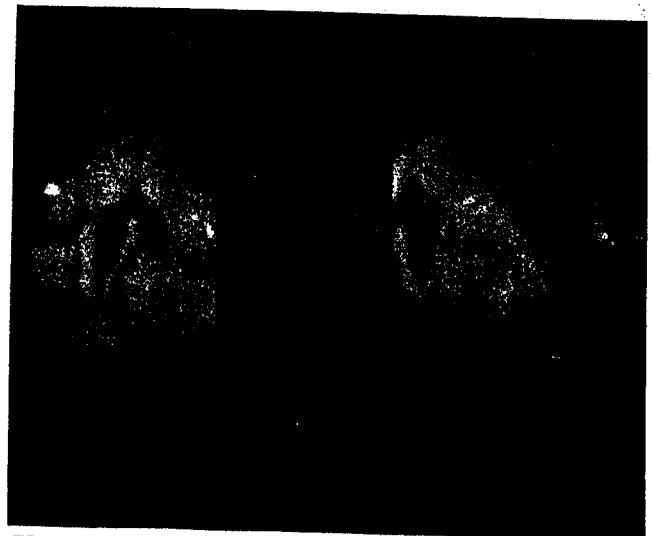


FIG. 1. An example of a pair of stereoscopic images of the larynx recorded side by side (still frame from a 16-mm film at 60 frames/s).

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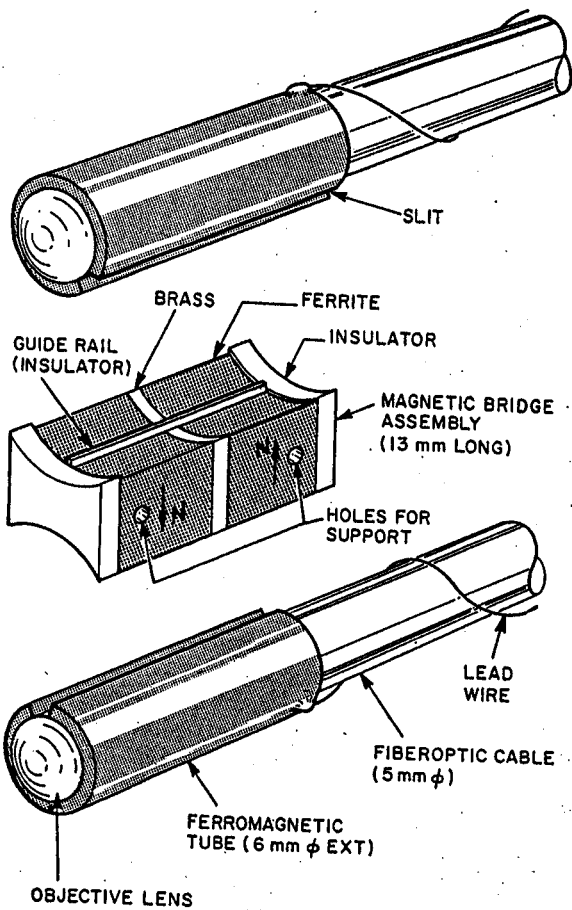


FIG. 2. The tips of the stereo-fiberscope and the magnetic bridge for joining them.

for our purposes in (1) optimizing adhesive force for joining the cable tips tightly together, (2) localizing the magnetic force so that the tips are pulled into position only when they are placed in the immediate vicinity and ready for the joining process, without causing problems in this delicate process within the pharynx. After the cable tips are visually confirmed to be located appropriately (through manipulation of the cables outside the nostrils), the magnetic bridge, supported at two small holes by a supporter, is inserted through the mouth. Due to the magnetic force, the bridge automatically slips into position between the tips, and its exact position, if not acquired already, is obtained through readjusting the cables remotely outside the nostrils. Steps at the ends of the bridge secure the final stable positioning of the cables relative to the bridge. A thin guide rail on each concave surface of the bridge fits into the slit of the sheath to secure a fixed angle of the lens with respect to rotation around its axis. A small piece of metal inserted between the two magnetic pieces serves as an electrode for electrically monitoring appropriate positioning of the object lenses during the abutting process and also through the experimental session. For this purpose, in the present version of the stereo fiberscope, the sheaths are insulated from the housing structures of the objective lenses, and thin lead wires are attached to the sheaths, the other ends of the wires being connected to a resistance

measurement device, which records a contact signal along with the sound on magnetic tape.

A string is securely attached to the magnetic bridge assembly as a whole, partly for safety and partly for facilitating the removal process after the experiment. In removal, one of the optic cables is pulled apart from the bridge, through manipulation outside the nostril, and then the bridge can be pulled out very easily. The present model of fiberscope has a set of remote manipulators for the tip-angle adjustments. The magnetic force between the bridge and the cable tip is significantly weaker when only one of the cable tips is in contact and the magnetic circuit is open.

Measurements are made by first projecting the filmed images onto the surface of a semitransparent digitizing tablet from the back and visually identifying the same landmark in both images. By indicating the positions of these landmarks using a stylus associated with the digitizing tablet, the experimenter inputs their coordinates to a laboratory computer. The computer then performs the calculations to locate these landmarks in three dimensions with respect to the fiberscope tips. The description of a three-dimensional image is built up by measuring several points (such as the anterior commissure and the vocal processes of the larynx).

The geometrical considerations for the measurement theory are indicated in Fig. 3. The two fiberscope tips are assumed coplanar, and are mutually inclined to a midaxis by a small angle α . The distance between the optical axis at the tips is R . A rectangular coordinate system is defined with origin midway between the two fiberscope tips. The z axis is along the midaxis. The x axis passes through the two fiberscope tips, and the y axis is perpendicular (out of the page). Vectors to the object point (x_p, y_p, z_p) form angles θ_L and θ_R with the left and right optical axes, respectively. These angles are related to x_p and z_p by the equations

$$\tan(\theta_L + \alpha) = \frac{x_p + R/2}{z_p}, \quad (1)$$

$$\tan(\theta_R - \alpha) = \frac{x_p - R/2}{z_p}. \quad (2)$$

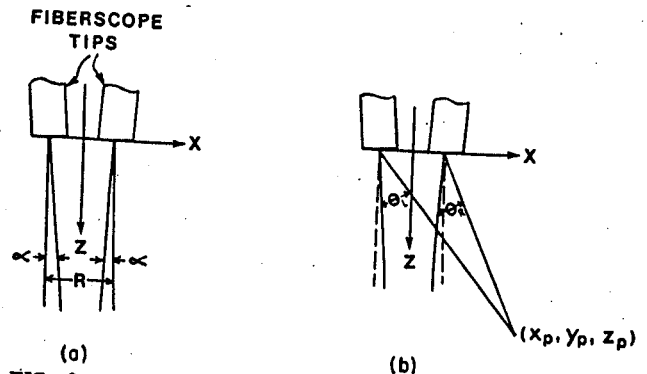


FIG. 3. Geometric quantities defined for computation of three-dimensional dimensions. The figure (b) shows a projection onto the x - z plane. The angles θ_L and θ_R are defined within the plane.

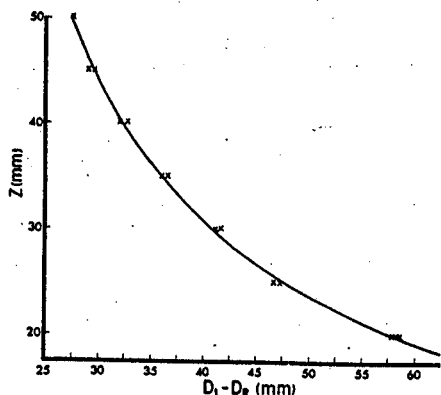


FIG. 4. Calibration of the estimated distance values between the object and the object lenses as a function of the observed measures $D_L - D_R$.

Therefore,

$$z_p = \frac{R}{\tan(\theta_L + \alpha) - \tan(\theta_R - \alpha)} \quad (3)$$

For small α , this can be simplified to

$$z_p = \frac{R}{\tan\theta_L - \tan\theta_R + 2\tan\alpha} \quad (4)$$

However, $\tan\theta_L$ and $\tan\theta_R$ are proportional to the distances D_L and D_R of the images of the point from the centers of the left and right optical fields, respectively. Therefore, the equation can be further rewritten

$$z_p = \frac{1}{K_1(D_L - D_R) + K_2} \quad (5)$$

where D_L and D_R are measured on the projection of the image. The constants K_1 and K_2 depend on the fiberscope tip geometry and the magnification of the projection system. Similarly, x_p is obtained from the relation

$$x_p = z_p K_3 (D_L + D_R) \quad (6)$$

The same multiplicative constant K_3 is also used to determine y_p from measured distances in the y direction on the images.

The calibration constants K_1 , K_2 , K_3 are empirically determined by photographing a grid at known distances. Figure 4 shows the results of a calibration run consisting of 14 independent measurements at seven known distances. The ordinate is the actual vertical distance, and the abscissa is the measured value $D_L - D_R$. The curve

for Eq. (5), with the constants K_1 and K_2 suitably determined, is plotted on this figure. The curve shows that these constants produce a vertical measurement error of 1 mm or less in all cases. The interlens distance between the centers of the two objective lenses was 8.9 mm in this case. A larger distance of course would result in a better accuracy.

The system has been used successfully for preliminary film recording sessions. Data obtained with this device will be reported elsewhere.

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¹The distance in question can be estimated via exact focusing of an appropriately designed lens system (see W. J. Gould, "Newer Aspects of High-speed Photography of the Vocal Folds," in *Dynamic Aspects of Speech Production*, edited by M. Sawashima and F. S. Cooper (Univ. Tokyo Press, Tokyo, 1977). This technique is applicable, however, only to static laryngeal gestures.

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