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A STUDY OF SENSOR ARRANGEMENTS FOR DETECTING MOVEMENTS AND INCLINATIONS OF TONGUE POINT DURING SPEECH

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ABSTRACT

A magnetic sensing system has great advantages in data collection with safety, ease, and high accuracy of non-invasive and hazardless measurements of articulatory movements. In attempts to develop such a magnetic sensing system as to detect static magnetic field induced by a small magnetic rod on the tongue surface, serious problems with tilting and lateral movements of the tongue are encountered.

This paper presents design improvements of articulatory measuring system and proposes a useful arrangement of sensors to reduce the measurement errors due to troublesome movements of the magnetic rod. For this purpose, several arrangements of the sensors were studied by computer simulation. Experimental results showed that errors can be effectively reduced by setting four sensors at each side of a subject's mandible where the sensors detect positions and inclination angles of the magnetic rod. At preliminary experiments, characteristic patterns of tongue movements including inclination due to deformation of tongue surface were observed on several test words.

I. INTRODUCTION

In order to construct satisfactory articulatory models of speech production, it is of great important to investigate relations between articulatory activities and corresponding acoustic characteristics of speech signals [1]. Most of the studies on articulatory behavior have been done by using X-ray technique [2]. Until now, many efforts have been made to develop useful methods with aim of data collection in a safe and relative inexpensive manner [3,4,5]. Among them, the method using a magnetic principle has great advantages in data collection with safe, ease, and high accuracy. Spatiotemporal information of a magnetic source can be obtained by measuring directions and intensities of the magnetic field. By applying a magnetometer sensor to a displacement sensor for sensing the magnetic field induced from the magnetic source, one can detect changes of magnetic field's intensities resulting from changes of a distance between the sensor and the magnetic source.

In this paper, we describe further improvements of articulatory measuring system using a static magnetic field induced by a small permanent magnetic rod. Using the measuring system sensing either static(DC) or alternating(AC) magnetic fields, serious problems with tilting movements of the tongue are encountered [6]. In the new system developed here, tilting problems were resolved by adding further sensor units for actively detecting these tilt angles.

II. MEASURING PRINCIPLE

Fig.1 shows a geometric configuration of a magnetometer sensor and a magnetic rod which is fixed on a desired point of the tongue surface. A magnetic field induced by the magnetic rod is detected by the magnetometer sensor. When two sensor units are used, positional information of the magnetic rod are determined given as the point of intersection of the equi-potential circles around each center of these sensors [7]. If the axes of sensor units and the rod are not parallel each other, the strength of the signal detected by the sensors decreased due to tilt angles and, as a result, the distance appears greater than the actual one.

The magnetic field intensity H_{zi}, Z-axis component of the intensity H_i at the sensor unit i ($i = 1, ...,m$), is given by the following equation:

$$H_{z_i} = -\frac{K}{r_i^5}\left\{ \left[r_i^2 - 3\left(z-c_i\right)^2\right]\cos\theta_z - 3\left(z-c_i\right)\left[\left(x-a_i\right)\cos\theta_x + \left(y-b_i\right)\cos\theta_y\right] \right\}$$

$$\left(i = 1, .., m\right) \qquad (1)$$

$$r_i^2 = \left(x-a_i\right)^2 + \left(y-b_i\right)^2 + \left(z-c_i\right)^2$$

$$\cos\theta_z = \sqrt{1 - \cos^2\theta_x - \cos^2\theta_y}$$

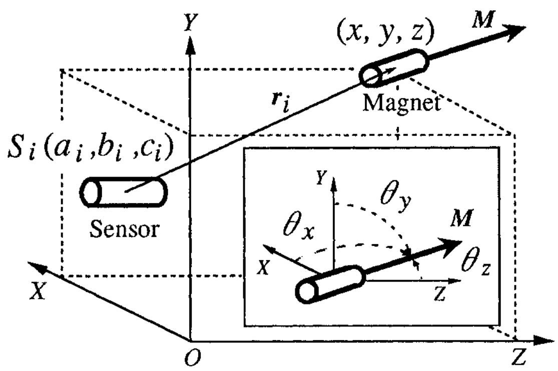


Fig.1 Geometric configuration of a magnetic rod (x, y, z) and magnetometer sensors (a_i, b_i, c_i).

Each discrepant angle of the rod's axis from the coordinate axes of (X, Y, Z) is denoted by $(\theta_x, \theta_y, \theta_z)$, respectively, as shown in Fig.1. From preliminary experiments, linear-relationships could be approximately obtained between output voltages of the sensors and magnetic field intensities, and therefore field intensities were easily transformed into output voltages of the sensor. In order to find unknown four parameters ; the position (x, y) of the magnetic rod and its tilt angles (θ_x, θ_y), by using output signals of sensors, it is necessary to solve the following non-linear equation based on the equation (1).

$$F_i\left(x, y, \theta_x, \theta_y\right) = \left(V_i - \beta_i\right) + \frac{G_i}{r_i^5}\left\{\left[r_i^2 - 3\left(z - c_i\right)^2\right]\sqrt{1 - \cos^2\theta_x - \cos^2\theta_y} - 3\left(z - c_i\right)\left[\left(x - a_i\right)\cos\theta_x + \left(y - b_i\right)\cos\theta_y\right]\right\} = 0 \quad \left(i = 1, .., m\right) \tag{2}$$

where V_i is the output voltage of the sensor i, and G_i and β_i are constants concerning with characteristics of the sensor i and the rod.

Solutions of the above equation were found by using the Newton's iterative method. In order to determine unknown four parameters $(x, y, \theta_x, \theta_y)$ of positional information of a permanent magnetic rod, more than four sensor units are necessary in the system.

As shown in eq.(1) or (2), as well as the parameters of tilt angles, sensing characteristics of the sensor are also changed by the parameter $| z - c_i |$, which is a relative displacement from the measuring plane (X - Y plane). When the displacement from the measuring plane is small, effects of the tilting parameters,(θ_x, θ_y),on output signals of the sensors are reduced. By applying this low sensitive characteristics to sensor arrangements, it is possible to realize a measuring system which has a low sensitivity to tilting movements of the rod. This is a case of two-point measuring system for tongue movements previously reported [8].

III. CONFIGURATION OF SENSORS

In order to solve the non-linear equation (2), these tilt angles should be actively detected by adding several sensor units. In this case, it is desired to design arrangements of sensors where large output signals are obtained when the rod tilts. This configuration of the sensors is shown in Fig.2, where four pairs of sensors are arranged at each side of a subject's mandible.

When the rod deviates from a measuring plane (as a reference) along the Z-axis, intensities of magnetic field induced by the rod change and therefore, positions of the rod are estimated to near to or far from the measuring plane corresponding to the direction of rod's deviations. In order to minimize effects of this deviation on the sensing characteristics, we proposed a symmetrical arrangement of the sensors, that is each pair of sensor units are set on opposite sides, as shown in Fig.2.

Fig.3 (a) and (b) show resultant error characteristics on positions(a) and angles(b) of the rod with $| z - c_i | = 100$ mm. For comparison, dotted lines in the figures show estimated errors when 4 sensors are set at only one side (left or right) of subject's mandible. Assuming that each angles are as follow; $\theta_z = 10^\circ$, $\theta_x = 90^\circ$, and $\theta_y = 80^\circ$, an allowable displacement from a reference ($Zg = 0$) is estimated to be within the relatively wide range of -10 ~ 4 mm at the limited error of 1 mm. When the sensors are set at either left or right side of the mandible, this displacement is estimated to be narrow range within -1 ~ 1 mm as represented by dotted lines in Fig.3.

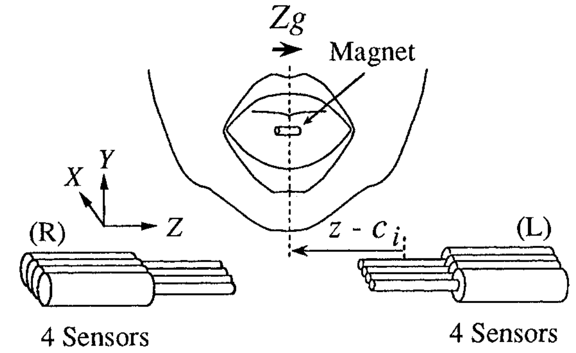


Fig.2 Arrangements of magnetometer sensors for monitoring positions (x, y) and tilt angles (θx, θy) of a magnet.

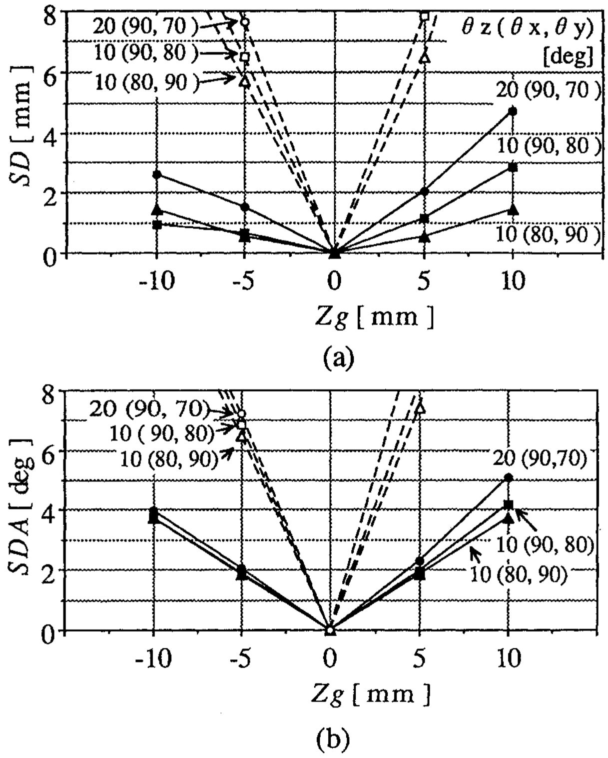


Fig.3 Detection errors caused by lateral movements(Zg). (a) position (x, y), (b) angle A (= θz) , see Fig.5.

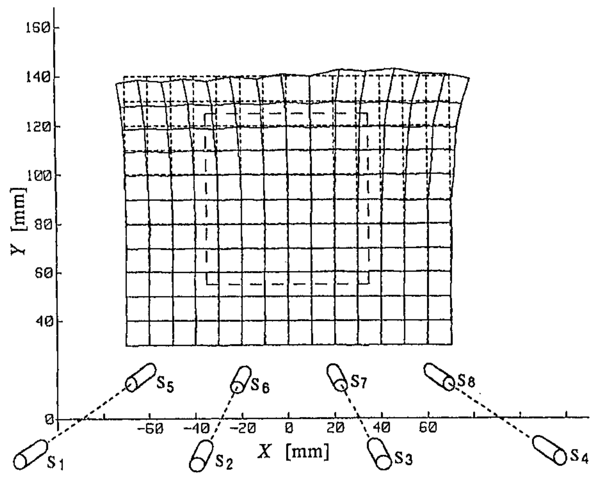


Fig.4 Empirical calibration pattern of the measuring system.

Fig.4 shows an empirical calibration pattern of the measuring system when 4 pairs of sensors (S_1-S_5, S_2-S_6,....,S_4-S_8) were set as shown in Fig.2. Dotted lines show theoretical patterns for rod's positions and solid lines show those of solutions deduced by solving the non-linear equation of (2). The calibration pattern was considerably deformed and large deviations from theoretical values can be seen primarily around upper region. However, since movements of the tongue seldom exceed a 3-cm range, a useful area (60 x 60 mm^2) enclosed with dotted lines is wide enough for measuring tongue movements during speech. In this area, a standard deviation of the calibration pattern was estimated at 0.64 mm. A detection error associated with tilt angles was sufficient small and its standard deviation was estimated at 0.22°.

IV. EXPERIMENTS

New parameters were introduced for understanding easily and intuitively tilting postures in articulation of the tongue. Transform equations from the parameters (θ_x,θ_y, θ_z) to new ones (A_x, A_y, A) are expressed as follows:

$$A_x = \tan^{-1}\left\{\frac{\cos\theta_y}{\cos\theta_z}\right\},\quad A_y = \tan^{-1}\left\{\frac{\cos\theta_x}{\cos\theta_z}\right\}$$
$$A = \theta_z \qquad (3)$$

where A is a deviation angle of the rod's axis from the Z-axis. Both A_x and A_y, which are components of the angle A, correspond to rotational angles around X- and Y- axes, respectively. These relations are shown in Fig.5 with the tongue posture and the magnetic rod.

By using this system, articulatory parameters have been measured on the tongue point of approximately 25 mm backward from the tongue tip, where the permanent magnetic rod (diameter 2 mm, length 10 mm) was set as a pellet.

Fig.6 shows examples of time patterns of tongue point movements during utterances of (a)[etete] and (b)[ekeke]. Each symbol in the figure relates to articulatory displacements and tilt angles of the pellet on the tongue as shown in Fig.5; (H: posterior-anterior, V: superior-inferior, VEL: velocity, A: deviation angle between the rod's axis and the Z-axis, A_y and A_x: projected angles of A onto a X-Z (horizontal) plane and a Y-Z (frontal) plane). When the rod's axis is parallel to the Z-axis, each value of A, A_x and A_y is equal to 0°. In the figure, enveloped signals of speech sounds were also shown as 'AUDIO'.

Table 1 shows variations of tilt angles which were evaluated in the period marked by a horizontal bar (|—|) as shown in Fig.6.

In the case of [etete], angle A_x was smaller than A_y through the period and the rod's axis was almost parallel to the horizontal plane. However, a variation of A_x was slightly greater than that of A_y as shown in the table; A_x:8.0°, A_y :5.9°. The case of [ekeke] showed a remarkable difference of variations between A_x and A_y. Angle A_x had the variation of 9.5° in contrast to the relatively rather small variation (2.4°) of A_y. This result

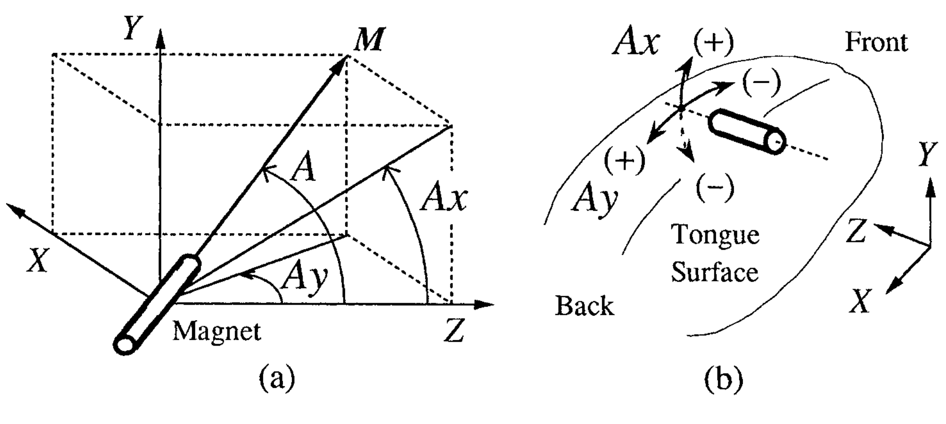
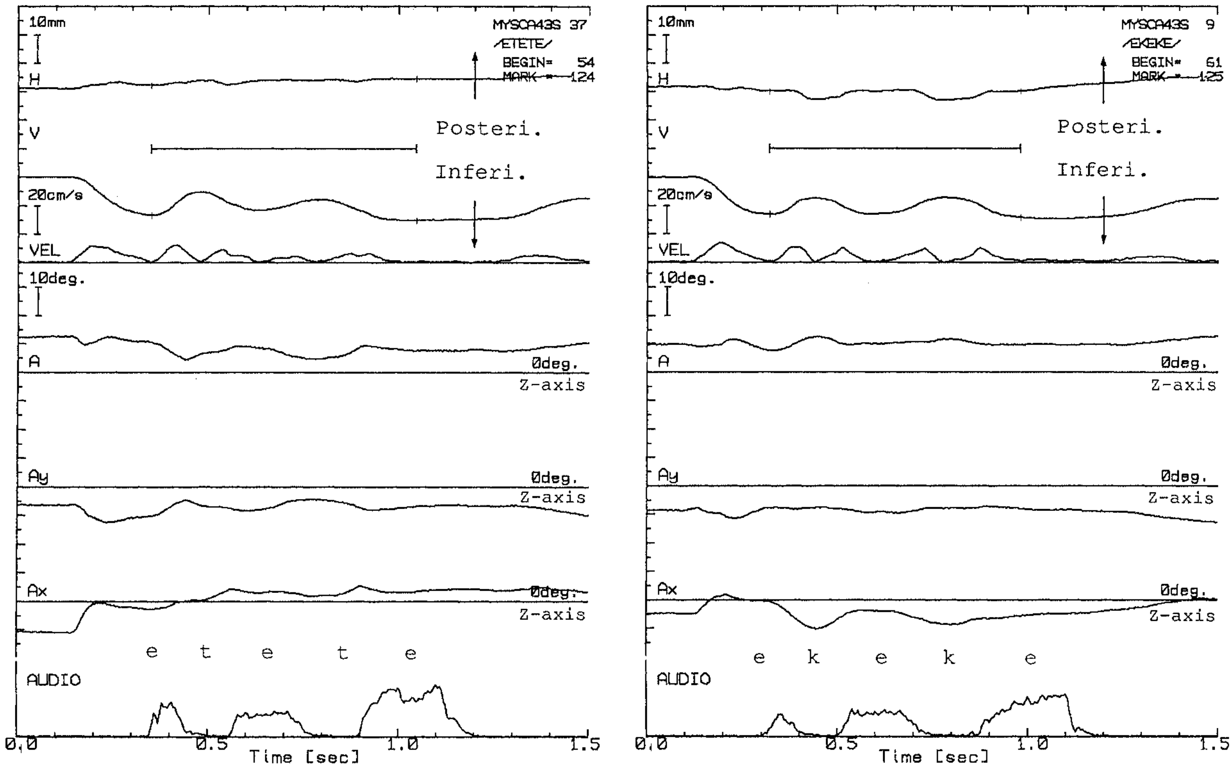


Fig.5 Definition of tilt angles of a magnet(a) and schematic diagram of the magnet on the tongue surface(b).



(a) (b)

Fig.6 Movement time patterns of the tongue point movement during utterances of (a)[etete] and (b)[ekeke].

Table 1 Variations of tilt angles.

		Average	Variation
[e t e t e]	*A*	7.3 °	5.9 ° (4.6°~ 10.6°)
	Ay	-6.7 °	5.9 ° (-10.2°~ -4.3 °)
	Ax	2.3 °	8.0 ° (-2.7°~ 5.4 °)
[e k e k e]	*A*	10.3 °	4.9 ° (7.6 °~ 12.5°)
	Ay	-8.1 °	2.4 ° (-9.5 °~ -7.1 °)
	Ax	-6.2 °	9.5 ° (-10.1 °~ -0.6 °)

shows that the rod primarily tilted within a vertical plane during the utterance. A change of a tongue posture related to the articulation of consonant [k] could be seen clearly in the time pattern of A_X.

Thus, the system enabled us to measure tongue movements including inclination due to deformation of tongue surface with high accuracy.

In this paper, an effective sensor arrangement was proposed to reduce the measurement errors cased by tilting and lateral movements of the magnetic rod. Using the sensing system with static magnetic fields is especially suitable to collect large amounts of data without extraneous substances, such as detector-coils and lead wires which are used in other magnetic sensing system with alternating fields.

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