Recording of mandibular movements by intraorally placed light emitting diodes

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In order to evaluate an opto-electronic system for recording mandibular movement a simulator and clinical pilot study was performed. The method was based on light emitting diodes (LED) and a photodetector system. One LED was placed intraorally and one on the forehead, the latter acting as reference. When the light spot is focused on the detector surface a photocurrent will occur. This current can be used to obtain two signals linearly related to the x and y coordinates of the LED. By using two detectors the three-dimensional coordinates of a movement can be calculated, consequently also the z-coordinate. In the simulator experiment the method was shown to have a satisfactory precision and good reproducibility. The results from the clinical test indicated that it is possible to measure and record mandibular movement with a minimum of external influence to the test person.

Key-words: opto-electronics; human

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Hitherto, an accurate and simple method for continuous recording of chewing movements has not been available. Considerable experimental difficulties have been encountered when trying to obtain recordings in three dimensions of mandibular movements in a coordinate system stationary with respect to the head of the subject. These problems have been discussed thoroughly by *Bewersdorff* (1969). The methods previously employed have often had a disturbing effect on the test person, not only from fixation of the head but also from application of voluminous equipment to the oral structures. Such factors can undoubtedly influence the normal chewing patterns. Thus there has been no precise method for recording mandibular movements in which these disturbing influences on the habitual chewing pattern are minimized.

In the following, new instrumentation for recording mandibular movements will be described and the results of preliminary experiments will be reported.

MATERIAL AND METHOD

Technical description

General. A movement monitoring instrument was developed by utilising a position sensitive detector for registration of signals from light

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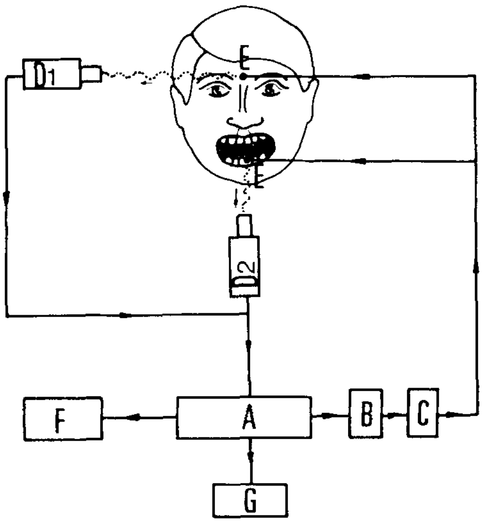

Fig. 1. The components in the selspot-system and the instrumentation connections for the measurements.
A. The main unit
B. Supply
C. The LED control box
D_1 D_2. The cameras
E. LED:s attached to the lower incisors and forehead of the patient
F. Computer
G. Ink recorder

emitting diodes (LED). The LED:s emit infra-red light which can penetrate soft tissue. The light from the LED:s was focused into a special semiconductor device which was mounted in a camera. The system components are shown in Fig. 1. The Main Unit takes care of electrical signal processing and the LED Control Unit (LCU) generates current pulses which power the LED:s. The camera contains the semiconductor detector and a preamplifier which amplifies minute photo electric currents from the detector. Using a measuring distance of 0.5 m and a lens system with a focal distance of 135 mm, a resolution of approximately 100 μ can be obtained.

An important part in the instrument (Selspot, manuf. by Selcom AB, Gothenburg, Sweden) is the position sensitive detector. This detector gives information about the position of any light spot which is focused on its surface. The light spot generates a current which will flow into resistive sheetings. The sheet currents are picked up by four electrodes. These output currents are measures of light intensity and position. By a mathematical procedure, the intensity factor can be cancelled, this procedure results in true position signals in two dimensions. The principle is shown in Fig. 2.

By activating one LED at a time, the position of a large number of LED:s can be determined. This technique is called time division multiplex. In the instrument described the position of up to 30 points can be measured. Each diode is activated during a very short period of time – 50 μs – and the repetition frequency for each diode is approximately 300 Hz. In this way, even very rapid movements can be measured. The bandwidth is approximately 100 Hz.

In the Main Unit the amplified signals from the camera are digitalized and all further signal processing is performed digitally. In this way high accuracy and reproducibility is obtained. The primary output from the Main Unit is digital but analog signals can be obtained optionally by installing a suitable number of analog modules (D/A-Converters). The coordinate signals can easily be stored on analog tape recorders or ink recorders. A more suitable method though, is to employ a computer by which signals can be stored directly.

By using two cameras, the three-dimensional coordinates of a movement can be calculated. The Main Unit accepts two cameras in true three-dimensional configuration, i.e. both cameras measure one diode simultaneously. Optionally, the Main Unit can be set up for handling three or more cameras in time division.

In a measuring set up described in this paper, two cameras were placed perpendicular to each other. For recording of the mandibular movement, a reference diode on the forehead was used. The head movements were then cancelled by subtraction. Perfect elimination of the head movements can only be obtained by using three reference diodes on the head. In this way the subject can move freely within a predetermined space. The size of the space is

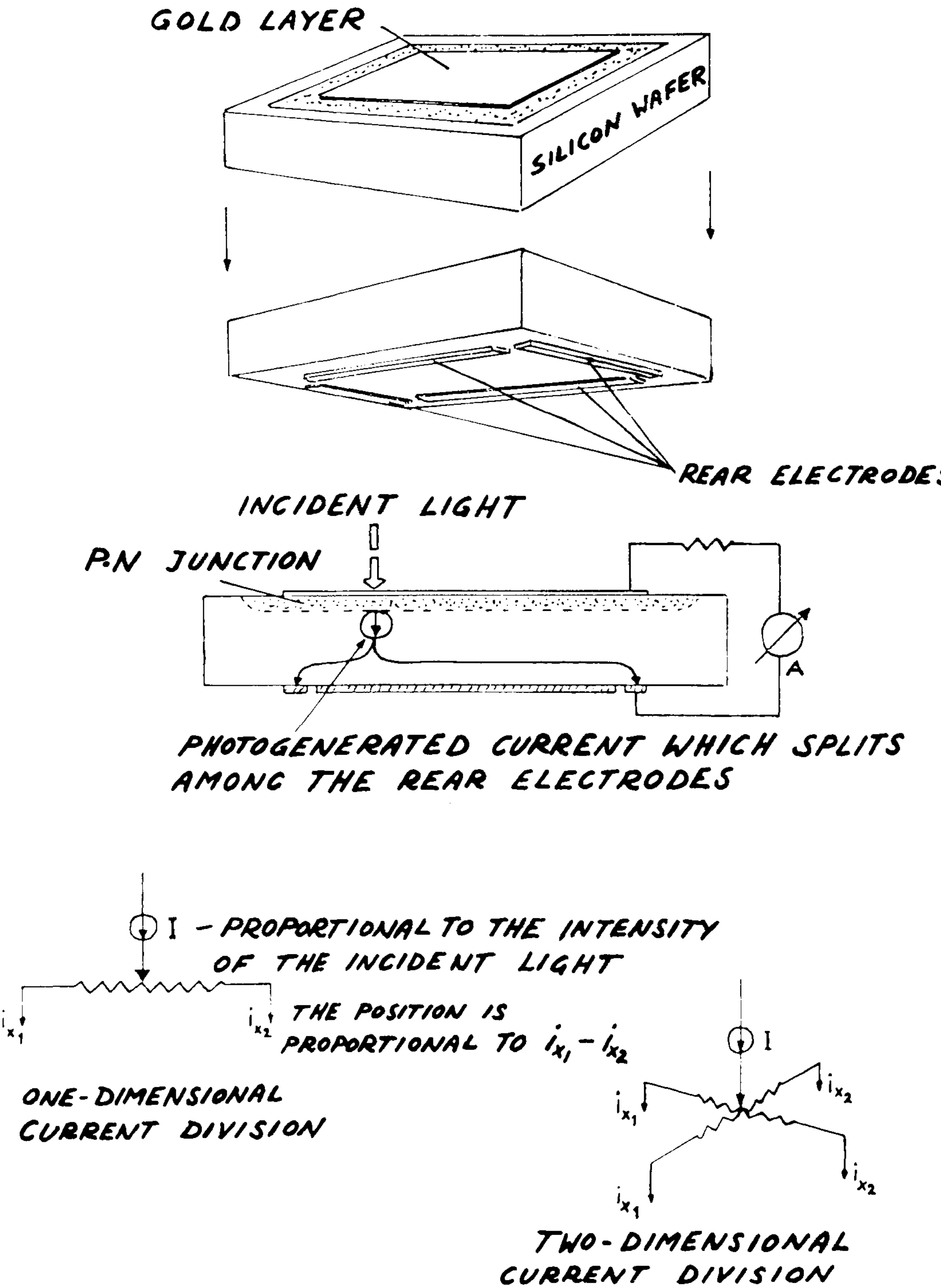

Fig. 2. The principle of the position sensitive photo detector.

mainly determined by the measurement resolution desired. The movement pattern in three dimensions must be calculated in a computer. The movements of the test person will, in principle, not influence the result. The three projections of the movement (frontal, sagital and horizontal) can be visualized after computer calculation on a three channel ink recorder or in arabic figures for manual handling and statistics.

Resolution. The signal input to the detector is obviously dependent on the optical system used, and therefore no general definition of the resolution at the measuring area can be given. Using a common objective (25 mm, 1:078), the position error is less than 2 mm at a distance of 5 m. At the same distance, the total measurable length is 2 m i.e. a resolution of about 1:1000.

Linearity. The detector non-linearity is about one per cent. The error for small viewing is usually below half a per cent.

Stability. The total temperature drift within the temperature range 20–70°C is less than 1 per cent at maximum input signal.

Bandwidth. The bandwidth is limited by the sampling rate, which is 315 Hz. The analog outputs have active lowpass filters with a cut off frequency of 100 Hz.

Clinical pilot study

A clinical experiment was made to examine the uselfulness of the system for recording of oral functional pattern. Two miniature light emitting diodes, diameter 1 mm, were attached to the subject. One diode was fixed by means of adhesive tapes to the forehead and the other was placed between the lower incisors by means of plastic substance. The LED on the forehead acted as reference diode for the mandibular movements. Thin titanium wire connected the LED:s to the LCU. The cameras were focused at the head of the subject at right angles. The arrangement is seen in Fig. 1. The distance between camera and LED:s was 50 cm. When chewing began the signals from both diodes were recorded by the camera system which gave an output of analog voltages corresponding to the three-dimensional coordinates of the two diodes. These signals were recorded on an analog tape recorder and an ink recorder at a paper speed of 2.5 cm/s. A graduated rule, where a diode was moved from the origin to the 5 cm mark, was used for calibration of the amplitude of the curve.

Determination of errors in the method of measurement

In order to study the true representation of a three-dimensional movement pattern, a 3-D simulator which could repeat its movements, was built (Fig. 3). A rheostatic control was applied to the motor for speed regulation. The above question was divided into two main issues: a) the repeatability of the Selspot measuring system at repeated recordings, and b) the effect on the amplitude of the curve when the speed of the simulator was changed. These two items were studied separately as follows.

Repeatability check. The reference diode was placed on the fixed column and the other diode on the moving ball (Fig. 3). The cameras were adjusted at right angles and then the simulator made 100 cycles at a constant speed. The output signals were recorded on a 3-channel ink recorder (Minograf Minor 3) with a paper speed of 25 mm/s.

Repeatability at varying speed. The experimental arrangements were the same as in the former test but the speed was varied by means of the rheostatic control. 100 cycles was performed.

RESULTS

Clinical pilot study

The purpose of the pilot study was to determine if this method is suitable for recording of mandibular movement patterns. Conse-

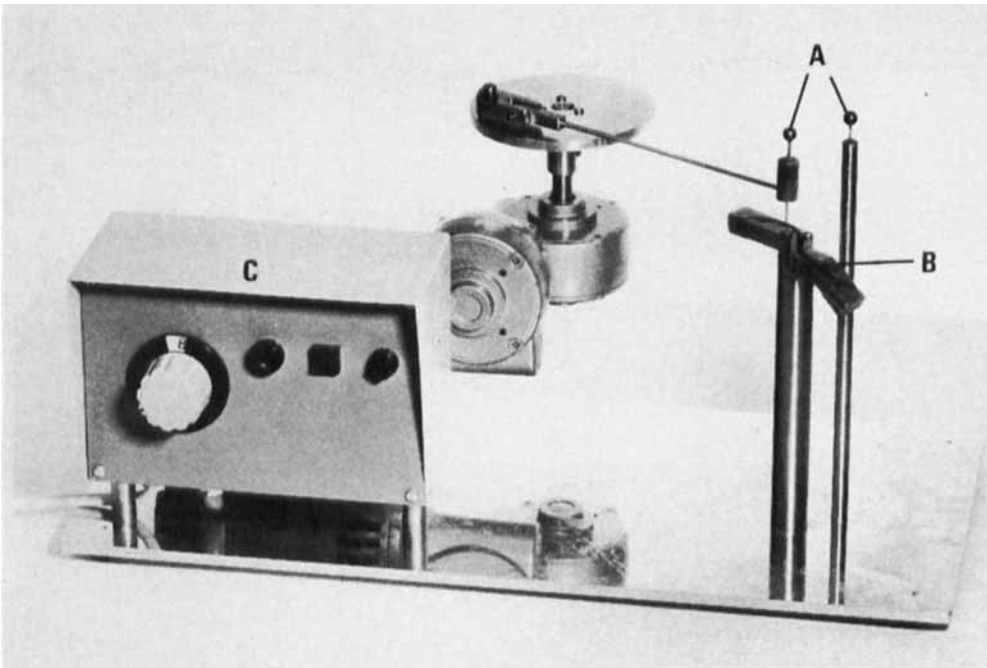

Fig. 3. The 3-D simulator
a) Attachments for the LED:s
b) S-curved track bent at an angle of 30°
c) Speedcontrolbox

quently the aims were not to measure or to compare any variables. A set of recordings can be seen in Fig. 4a, where the amplitude/time relation easily can be measured. The top curve shows the horizontal mandibular movement with respect to the reference diode, i.e. the x-coordinate. The next curve shows the vertical movement, the y-coordinate and the lowest curve shows the sagital displacement, the z-coordinate. As no brakes in the curve can be seen, the effect of the infra-red light emitted by the LED showed to be sufficient to penetrate the soft tissues surrounding it.

Determination of errors

Repeatability. The result can be seen to the left in Fig. 4b, where five translucent papers of measurement cycles chosen at random have been superimposed on each other and photographed. The figure shows a total coincidence of the curves. Consequently the repeatability can be assumed to be acceptable and free from technical errors in the monitoring system.

Repeatability at varying speed. The 100 cycles were analysed as to the amplitudes of the curves which coincide regardless of the choice of speed (Fig. 4c). Accordingly speed variations in the moving object, to a certain limit, does not seem to affect the precision of the measuring system.

DISCUSSION

This pilot study has shown that the method described is suitable for recording mandibular

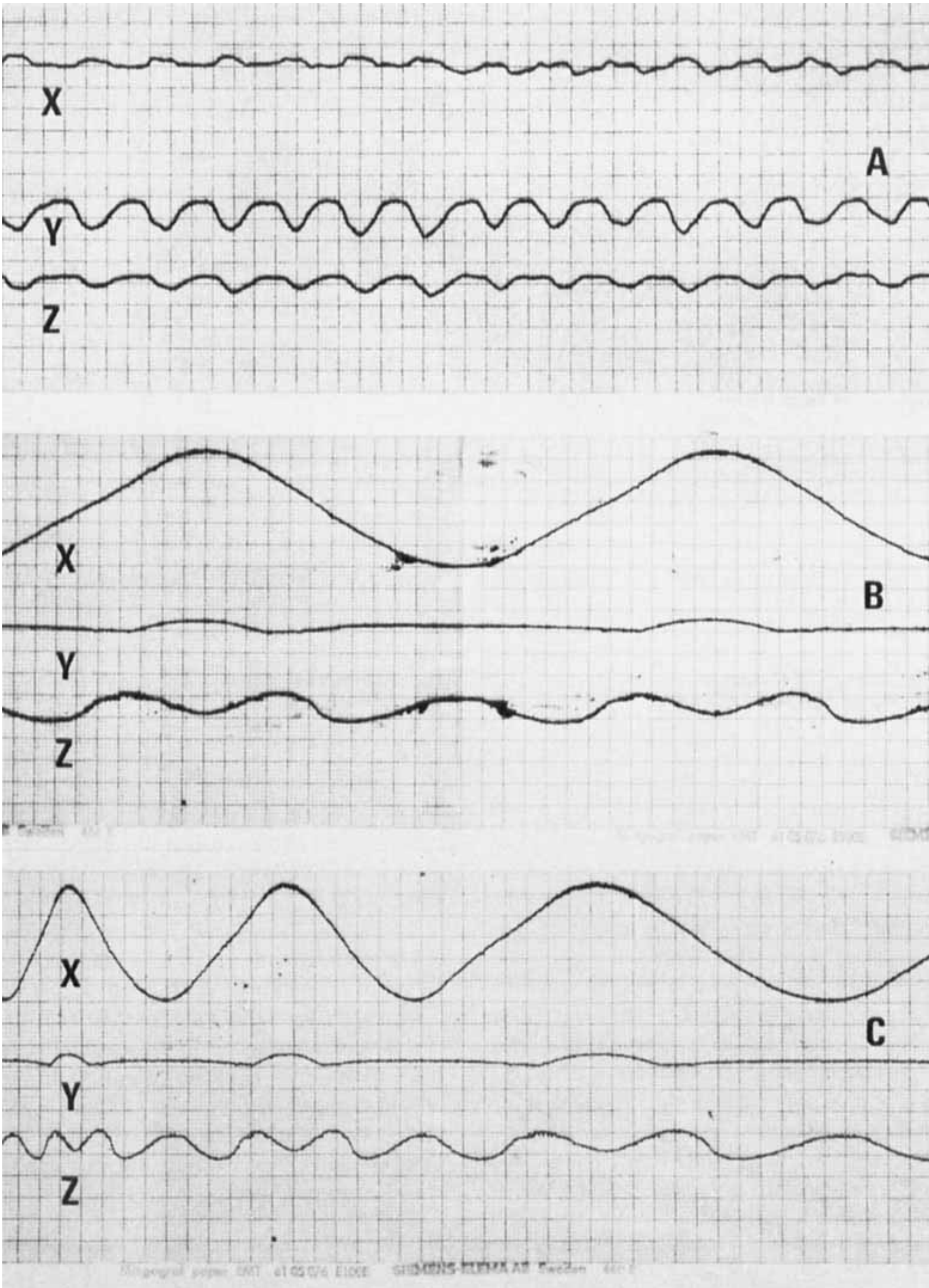
X
A
Y
Z
X
B
Y
Z
X
C
Y
Z

Fig. 4. Example of recordings
a) The X-Y-Z-curve of a person chewing hard bread
b) The left part shows five simulatorcycles superimposed on each other
c) Example of the simulator XY Z-curve at different speeds of the simulator.

velocity and movement patterns on chewing. It is reliable for use in a planned study and its operation is uncomplicated. Furthermore, the equipment is mobile and may therefore be used in surroundings which may disguise the experimental situation thereby decreasing extraneous influences on the normal behaviour pattern. The extent to which the test surroundings, the LED:s and the thin wires increase the subjects awareness of chewing and disturb the habitual movement pattern is difficult, probably impossible, to detect. In the results of the clinical pilot study errors due to minute rotating movements of the head are not excluded but by use of three reference diodes it is intended that this error will be excluded and the test person allowed to move his head in all directions without any influence on the monitoring of the real mandibular movements in three dimensions.

In this pilot study the precision was high and the smallest movements that can be recorded by the system (in this instrumentation set, up to 0.09 mm) are probably satisfactory for clinical studies. In material-testing applications one may probably require higher precision. This can be obtained by moving the cameras closer to the LED:s and/or using a lens with a longer focal length. The adaptation of the system to computer techniques makes it possible to obtain a maximum of information with a minimum of manual work.

This system has several possible applications in dental research where oral functional movements are to be studied: for example, the deformation of bridges and other prostheses during function, full denture mobility testing or even in edentulous cases where small diodes could conceivably be implanted in the mandible. Another advantage of this system is, that the presentation of the results can be made analogue, digital or directly graphically visible. A simulator study, now in progress, will establish whether the object-fixed coordinate system consisting of three LED:s enables the maintenance of sufficient precision for clinical use. In this study, in which computer processing will be used the system error will be determined numerically and, in addition, the refraction of the light beam passing the skin will be calculated. The method seems to be well suited for the high precision evaluation of intra-individual changes in oral performance after different forms of oral rehabilitation, and in the future a study will be performed in order to make correlations between the chewing cycle, mandibular velocity and acceleration before and after rehabilitation with bridges and prostheses and after TMJ therapy, eventually to be combined with EMG.

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