OPTOPALATOGRAPH: DEVELOPMENT OF A DEVICE FOR MEASURING TONGUE MOVEMENT IN 3D

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ABSTRACT

This paper identifies and investigates potential sources of measurement error using a prototype of a device for measuring tongue-palate distance, contact and pressure across the whole of the hard palate. The Optopalatograph (OPG) is similar in principle to the Glossometer and similar in configuration to the Electropalatograph. It uses optical fibres to relay light to and from the palate and distance sensing is achieved by measuring the amount of light reflected from the surface of the tongue. A high power halogen light source is currently used to compensate for light attenuation and losses in the system. This source is not readily switchable and we evaluate the error in the measured light intensity when all the sources are on simultaneously. We conclude that the halogen-based OPG is a practical device with a worst case error of 10% in estimated distance values below 5mm

1. INTRODUCTION

The technique of measuring reflected light intensity to calculate the tongue palate distance was first proposed in 1978 by Chuang and Wang [1] and developed throughout the 1980's by Fletcher and McCutcheon [2]. They used a set of four LED/photodiode pairs imbedded along the midline of a false palate and gave it the name, Glossometer. The Optopalatograph by contrast uses optical fibres to transmit light to and from a false palate. The use of fibres results in a less cumbersome palate construction and enables many more measurement points to be provided. Crucially, this allows measurement points off the midline thus which providing data is unavailable from electromagnetic articulograph or x-ray microbeam apparatus. At ICSLP96 [3] we presented an outline of the device and demonstrated the efficacy of the technique. In this paper we will describe the practical issues of the prototype's development and demonstrate its operation.

The system is divided into three parts - the optopalate itself; a separate self-contained unit composed of the light source, the sensor array and the associated electronics necessary to convert the received signal into a form suitable for processing by a computer and a computer running software to analyse and interpret graphically the digital signals.

2. THE OPTOPALATE

The fabrication of a prototype optopalate is subject to the following main requirements:

- the body of the optopalate should be no thicker than that of a conventional electropalate,
- it should be possible to distribute receiving and transmitting fibres across the whole palatal surface.

The optical glossometer of Fletcher and McCutcheon [2] employs four sensors positioned along the midline of the artificial palate. The optopalates constructed during this investigation have incorporated an additional four sensors off the midline as shown in figure 1.



Figure 2: Plan and midsaggital cross section of the upper palate showing the OPG prototype sensor locations.

2.1. Estimating the maximum number of sensors

The question naturally arises as to how many fibre optic emitters and receivers can be distributed across the palate surface in practise. A realistic estimate has been arrived at in two ways: the first relies on the practical experience of building an optopalate, the second has been determined by the size of the cables leaving the optopalate.

The primary determining factor is the diameter of optical fibre to be used. In order to maximise the number of sensors we need to minimise the diameter of the fibres. The minimum diameter is limited by the level of light required to achieve the distance sensing effect. This in turn is dependent also on the intensity of the light source.

In a previous study [3] we used 1mm plastic optical fibres and achieved a result with high power Ga AS LEDs as sources. Reducing the diameter of the fibres to 0.5 mm reduces the light level from this source below the minimum necessary for operation and the current amplifier design produces no distance sensing response. Attempts were made to increase the power of the source by pulsing a larger current through the LED. Both red and infra red LED's were tried but no satisfactory response has been achieved. In order to achieve a response from optical fibres with a diameter less than 1mm it has been found that one possible solution is to use a 10W halogen light source.

In order that the optopalate be as thin as possible no fibre should run over another when they are affixed to the palate surface; this also eliminates the risk of damage to the fibres occurring at the crossover point during and after construction. Consequently the fibres are laid in a single layer except at the point near the rear molars where they are gathered together to leave the palate in a cable - the fibre diameter thus restricts the number of fibre pairs that can be used. The eight fibre pairs that have so far been used have been accommodated on the palate surface easily, a further twelve could probably be distributed on the test palate (which is broad). On this basis, practical experience suggests an upper limit of twenty fibre pairs per optopalate if 0.5 mm fibres are used.

The cables that carry the bundles of optical fibres from the optopalate cannot have too large a diameter. An effective method of packing the fibres in the cable is to have a central fibre surrounded by six others. If this pattern is continued, then successive layers contain 1, 6, 12, 18.... fibres, there then being correspondingly 1, 3, 5, 7.... fibres across the largest diameter. With 0.5 mm fibres and 5 fibres across the cable, its inside diameter would be 2.5 mm. If the cable sleeving was of the order of 0.25mm thick then the overall cable diameter would be 3 mm which is probably a realistic upper limit for an acceptable size. Such a cable would contain 19 fibres and since there are two such cables leaving the optopalate this means that with, 0.5 mm fibres, an upper limit of 19 fibre pairs is possible. Both practical experience and an estimate based on cable size yield, effectively, the same number of fibre pairs as an upper bound. It can be confidently expected that any given practical optopalate will have N fibre pairs where 8 < N < 20.

3. THE INFLUENCE OF SECONDARY LIGHT SOURCES

The current OPG prototype consists of a 10W halogen light source and an optopalate with 8 0.5mm fibres arranged as shown in figure 1. Unlike a light emitting diode, a halogen light cannot be switched on and off quickly and a mechanical shuttering system is difficult to synchronise with the receiver electronics. Although, it is clear that having all the sensor transmitters on at the same time will complicate the distance calculation, it is less clear to what extent the accuracy of the device will be affected.

3.1. Theoretical study

We would like to predict the influence on the readings given by a sensor pair of a secondary optical fibre source some small distance away.

To do this we have calculated the received power in terms of the radius (*b*) of the transmitting and receiving fibres, the separation (*x*) of the transmitting and receiving fibres, the beam spread (α) from the transmitting fibre, the suface reflectivity (ρ) and the distance (*h*) from the reflecting surface.



Figure 2: Diagram of sensor showing transmitter (Tx) and receiver (Rx) fibres and the circular illuminated region on the reflecting surface.

In this model we assume that the light rays exiting the fibre do so as if they originate from a source point a distance *b*cot α beyond the end of the fibre which results in a beam spread angle of α . ie. radius (a) of the beam at height *h* is *b*+*h*tan α .

Integrating over the illuminated surface gives the gives equation 1 in a similar form to that provided by Chuang and Wang [3] but where the constant is here dependent on the diameter of the transmitting and receiving fibres.

$$P = P_0 k \frac{h}{\left(h^2 + x^2\right)^{\frac{3}{2}}} (1 - \phi)$$
 Eqn. (1)

where k is a constant which depends on the fibre diameter, the reflectivity of the surface and the angle of beam spread.

$$k = \frac{\rho b^2}{4} \frac{\tan^2 \alpha}{1 - \cos \alpha}$$
 Eqn. (2)

and where

$$\phi = \frac{3}{4} \left(\tan^2 \alpha + \frac{a^2}{2} \frac{\left(2h^2 - 3x^2\right)}{\left(h^2 + x^2\right)^2} \right)$$
 Eqn. (3)

and

$$a = b + h \tan \alpha$$
 Eqn. (4)

The term ϕ can ,to a first approximation, be considered a constant with a value of

$$\phi \approx \frac{3}{2} \tan^2 \alpha$$
 for x < h and h > b Eqn. (5)

From a 0.5mm optical fibre we estimate the angle of beam spread to be approximately 25°. Using this value for α and using the constant approximation for ϕ

$$k(1-\phi) = 0.024$$
 Eqn. (6)

Now we can plot the theoretical distance sensing curve for a transmitter/receiver separation x of 0.5mm representative of the sensor pair. On an evenly distributed 8 sensor palate an adjacent sensor pair will be approximately 10-15mm distant. The influence of a single secondary transmitter on a sensor is plotted by setting x = 10mm. Figure 3. shows the theoretical curve for a single sensor and the cumulative effect of a secondary transmitter. In the centre of the optopalate a sensor may be surrounded by 6 transmitters Figures 4 and 5 show the sensor readings when 6 equidistant transmitters are positioned x = 15mm and x = 10mmrespectively. The latter indicates a 20% underestimation of the distance at 5mm due to the additional light. For our 8 sensor prototype however, figure 4 is more representative showing a 10% underestimation.



Figure 3: A- The received power from at the sensor due to the sensor transmitter (x = 0.5mm). B- The received power at the sensor due to a secondary transmitter (x = 10mm). C- Combined received power of primary and secondary sources.



Figure 4: A- The received power from at the sensor due to the sensor transmitter (x = 0.5mm). B- The received power at the sensor due to 6 secondary transmitters (x = 15mm). C- Combined received power of primary and secondary sources.

3.2. Experimental measures

An arrangement of 6 x 0.5mm transmitter fibres at x=10mm from a sensor pair and measuring the output signal from the OPG amplifier reveals experimental readings which match the theoretical model well (Figure 6). All readings were subject to +/- 0.25 mm distance measurement error.



Figure 5: A- The received power from at the sensor due to the sensor transmitter (x = 0.5mm). B- The received power at the sensor due to 6 secondary transmitters (x = 10mm). C- Combined received power of primary and secondary sources.



Figure 5: A- The measured power from at the sensor due to the sensor transmitter (x = 0.5mm). B- The measured power at the sensor due the combination of the sensor transmitter and 6 secondary transmitters (x = 10mm). C,D- Theoretical predictions for A and B (scaled to fit).

4. CONCLUSIONS

The influence of secondary transmitters on a given sensor reading depends on their number and distance. In

the current 8 sensor prototype palate the central sensor can be predicted to be the most influenced with a 10% underestimation at 5mm. The discrepancy increases for larger distances and this would therefore suggest that the range of an optopalate designed with all the transmitters permanently on is restricted.

The measurement discrepancy as discussed so far can be interpreted as the worst case error for the device and in practice should be expected to perform better since it would be calibrated with all the transmitters on. Factors such as nonparallel alignment of transmitters and nonplanar surface as encountered in practice produce a high degree of uncertainty and more complex modelling is required to predict how much better the system can perform than the baseline specified in this paper.

In order to minimise the diameter of optical fibres used to transmit light to and from the optopalate in our current prototype we have maximised the intensity of the light source. The current prototype uses a 10W halogen source and this permits distance sensing using 0.5mm fibres. Eight sensors have been mounted in an artificial palate but it is estimated that a final version is likely to have 16 sensors with 20 being an upper limit.

The implications of having all the transmitters permanently on rather than switching each one on in turn are complex but we have shown that a prototype of this design can at least operate at a similar accuracy to a switched design in the range 0-5mm.

We are continuing to study the properties of a halogen based optopalate but we are also planning amplifier design improvements which may permit the use of LED sources.

5. REFERENCES

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