A technique for enamel diagnostics using results of the infrared optical non-destructive control examination

Bustillo Díaz M.M., Mehrdad Roham, Anait Gabrielyan, Melekhin V. F.

Dept. of Cibernetica Tecnica, Automatización y Técnicas de Computación
Information Systems in Economics and Management
Dept. of Economics and Management
Saint-Petersburg State Polytechnical University
Polytechnicheskaya 29,195257 Saint-Petersburg, Russia

Abstract: A safe technique based on the infrared optical non-destructive control (IONC) method for diagnostics of enamel defects is suggested. The technique permits diagnostics of a dental disease at very early stages, when the enamel recovery is still possible. The minimum dimensions of the defect area that should be found have been determined by processing the data received from professional dentists. For each type of enamel defects including caries and demineralization the standard values have been determined on the basis of the laboratory research of the IONC method. The information obtained by the IONC method is processed by fuzzy modelling in MATLAB. The linguistic rules are defined on the basis of analysis of information received from dentists who answered a specially prepared questioner. The diagnosis results received using the technique are shown.

Keywords: diagnosing system, fuzzy system, methodology, algorithms, diseases.

1 Introduction. The importance of diagnostics at the early stages of a disease.

Methodology and technology of dentistry diagnostics are not properly developed. There are no means that permit dentists to recognize diseases at early stages when it is still possible to recover the teeth without the surface destruction. It is very important to develop new diagnostic techniques especially for early stages of such diseases as demineralization and initial caries so that preventive treatment could be provided.

At present the main method for enamel analysis is a mouth examination. After a simple visual examination a professional suggests medical rehabilitation or surgical intervention if he has found pathology. The preventive treatment consists of mouth and teeth cleaning as well as fluoride treatment. Dental diseases at early stages are almost impossible to notice consequently the preventive measures are not prescribed in time. It is impossible to prescribe treatment for a condition that has not been found and evaluated, especially if there are no symptoms. For diagnostics dentists usually consider the colour and shape of the defects. But at early stages of a disease defects are small and it is difficult to notice them during a visual examination.

Treatment that involves destruction of healthy areas of enamel results from late diagnoses, which are caused by several reasons. Firstly, patients are not used to preventive dentist treatment and visit dentists only when they already suffer from teeth ache – a sign that some teeth are infected or have deep caries. Secondly, even when a patient comes for a routine inspection but does not voice any complaints the dentist usually comes to a conclusion that the patient's teeth are healthy. Yet, the teeth can be already affected by caries which starts with microscopic grey dots that are unnoticeable against the enamel surface and cannot be found with the unaided eye.

The problem is that if caries is not stopped, later it will be impossible to treat it without destruction of healthy tissues. If demineralization is not treated in time, later it leads to caries development. In such cases the dentist’s conclusion that the patient is healthy has nothing to do with negligence. It is impossible to diagnose a condition that has no signs and that the patient cannot feel. That is why diagnosis at early stages requires special engineering techniques that broaden dentists' abilities to examine the enamel.

Objectives. The article describes a diagnostic technique for early stages of dental diseases based on a new, safe method of
infrared optical non-destructive control (IONC) of enamel surface. The minimal detectable defect dimensions are determined considering the resolution limits of the modern technologies that are used for the IONC method, the results of statistical processing of the experimental data, and dentists’ estimation. We suggest a method (algorithm and tools) for processing of the initial data received from the measuring transducer and principles for decision making regarding the diagnosis.

2 The IONC method. Determination of the ranges of measured values for different conditions of enamel surface.

The IONC method uses a transducer that determines state of a quad in accordance with the intensity of a laser beam reflected from the surface in infrared band [1]. The reflected beam intensity is transduced into voltage level which is coded into digital format and passed for storage and processing. The set value range of the measured value code is (0 - 3.8).

The intensity of the reflected beam that is transduced into voltage is influenced not only by the condition of the surface it is reflected from (the useful information which is required from the received signal), but a number of disturbance interferences as well: accidental change of the angle between the beam and the surface, fluctuations of the transmitter and the receiver, environmental conditions, etc. Altogether these factors cause distortion and ambiguity of the information received.

Due to fortuitous distortions and ambiguity of the received information the data and processed by fuzzy modelling in MATLAB. The method is described below.

In order to determine the ranges of the transducer output code values that correspond to main classes of enamel defects a series of tests with statistical treatment of the results was carried out. At present stage of IONC diagnostic equipment development tests are run at experimental setup with extracted teeth without patients. Dentists had chosen 10 samples of teeth and indicated areas with enamel defects such as caries and demineralization. Over a thousand measurements for each sample have been carried out. After the statistical treatment of the results we received the following reference ranges for code values: for caries $P_C = 0.6 \pm 0.6 (0 – 1.2)$; for demineralization $P_D=3.0 \pm 0.3 (2.7-3.3)$. The whole range of code values is (0-3.8). The range (1.2 – 2.7) represents healthy enamel surface. The range (3.3 – 3.8) also represents healthy enamel surface which is especially smooth and lustrous. In accordance with the code value we determined the corresponding linguistic variables which represent the qualitative characteristic of the measurement: low, medium, high, and very high. Membership functions are specified by the described ranges. The diagnostics is determined by the following: low represents caries, high represents demineralization, medium and very high represent healthy enamel.

2.1 Evaluation of the IONC method resolution

According to dentists' expert opinion the minimum enamel defects that a professional can found with the unaided eye have linear dimensions from 250µm. Defects caused by demineralization at early stages are smaller. It is impossible to found demineralization defects of this size by the traditional methods.

The minimal linear dimension of a quad is limited by the gauge scanning pitch and is 50µm.

It is very important to discover demineralization defects at early stages because then it is still possible to regenerate the enamel structure by preventive treatment. According to dentists’ evaluation the size of defects (surface anomalies) that should be found is about 200µm. At this stage the preventive treatment is still possible including nutrition changes in order to prevent caries formation and enamel structure regeneration by providing deficient minerals in case of demineralization.

To discover the quads with enamel anomalies the comparative analysis of adjoining quads is needed (in order to eliminate random deviates). Every quad has 8 adjoining quads (two quads along 4 axes: vertical, horizontal, and 2 diagonal). Thus the minimal area of a quad that
is being diagnosed is: 150×150µm$^2$. This size perfectly answers dentists’ requirements.

3 Source data for finding areas with anomalies that were collected from dentists

Development of a system for defect detection and diagnostics requires obtaining specific knowledge from experts. Thus one of the priority tasks of this work was to collect and analyze dentists’ experience and knowledge. We need to use professional jargon to obtain reference information and transform it into the rules for making decisions regarding the measurement results and their processing. In order to create linguistic rules it is necessary to make clear how dentists describe the enamel defects and how they diagnose the enamel anomalies. In particular homogeneity of areas with defects is quite important. In order to determine all the points that are significant for automation of diagnostics a questioner for experts was developed.

The questions and answers given by expert dentists are listed below:

1. Can there be a healthy enamel zone in the middle of an area affected with caries?. Answer: No, it is impossible. However, an area of enamel affected with caries can contain a zone with demineralization. Demineralization is a stage of caries development.

2. What should be caries / demineralization ratio at a damaged enamel zone for the zone to be diagnosed as caries? Answer: More than 50% quads with caries reference value $P_C$ and less than 50% quads with demineralization reference value $P_d$. If this ratio is not true, the case cannot be diagnosed as caries.

3. What should ratio between demineralization, caries, and healthy tissue at a damaged enamel zone be for the zone to be diagnosed as demineralization? Answer: In accordance with the set quad dimensions there should be 70% Pd quads and there should be no more than one Pc quad. The rest of the quads in the area should have characteristics of healthy enamel.

These rules were used as the basis for linguistic rules.

3.1 Algorithm and organization of measurement data processing.

The surface scanning results for each quad make a rectangular $m$ by $n$ matrix: $\|x_{ij}\|$. Received unprocessed data are perturbed and contain measurement errors. The data matrix size depends on the measured teeth size. The measurement process is described in [1].

The matrix entry set: $X = \{ x_{ij} \}$, $i \in I$, $m$, $j \in I$, $n$ need to be separated into 3 subsets $X^c$ (diagnosed as caries), $X^d$ (diagnosed as demineralization), and $X^h$ (diagnosed as healthy tissue). Where $X = X^c \cap X^d \cup X^h$, $X^c \cap X^d = \emptyset$, $X^c \cap X^h = \emptyset$, $X^d \cap X^h = \emptyset$. This can be solved by step by step computation.

Step 1. Input of 3 entries of the matrix.

Input of data for processing is done into the lines of the templates (frames) shown in fig.1. Data are entered into i-line of the 1st (left) template and processed. First, $i := 1$.

![Fig. 1. data input into the system. (Heading: Quads. Inputs)](image)

Step 2. The line with entered data is analyzed: $(x_{11}, x_{12}, x_{13})$:

- For each element of the line the linguistic variable value is determined by membership functions. It is done by MATLAB. Fig.2 shows processing of entered code $x = 0.664$ using MATLAB fuzzy classifier. The membership functions
corresponding to the above mentioned ranges are shown.

Fig.2. Determination of the linguistic variable value at entering code $x_{ij}$

**Step 3.** After the linguistic variable values for all three codes $x_{ij}$ have been received, the linguistic variable value for the whole line is determined. This permits to determine the linguistic variable value of diagnostics on the basis of dentistry experts’ estimation and influence of the next neighbours. This linguistic variable values are: caries (c), demineralization (d), and healthy tissue (h).

If the received result is $h$, i value is modified: $i := i+1$ and the next line of the template is entered:

$$(x_{i1}, x_{i2}, x_{i3}) \quad \text{(return to step 1).}$$

If the received result is $c$ or $d$, it is a sign of an enamel defect. Then out of three elements the middle one singled out. Let it be the element $x_{ij}$.

**Step 4.** A set $X1$ is formed which includes $x_{ij}$ and 8 its adjoining quads:

$$X1 = \{x_{kl}; |k - i| \leq 1; \}, |l - j| \leq 1.$$  

**Step 5.** The linguistic variable values of diagnostics are determined for all members of set $X1$ using MATLAB accessories and membership functions, and consequently subsets $X1^c$, $X1^d$, and $X1^h$ are formed. These subsets’ cardinal numbers are determined: $n_c = |X1^c|, n_d = |X1^d|, n_h = |X1^h|$.

**Step 6.** A general diagnostic decision is made for set $X1$ in accordance with the following rules based on the above mentioned dentistry experts’ estimation:

- Caries - if $n_c \geq 5$ and $n_d \leq 4$.
- Demineralization - if $n_d \geq 6$ and $n_c \leq 1$.
- In other cases – healthy tissues.

This decision is accepted for all 9 elements.

**Step 7.** If the last entered line $i < m$, modification $i := i+1$ and return to the 1 step is made.

If $i= m$ and $j < n$ (the template has not included the last column), the template is shifted one column to the right (see fig.1), $i := 1$, return to step 1.

In this case elements of the 2nd and the 3rd column are processed again, but in different sets. If the results for some elements have changed, the new values are accepted. Such approach takes into consideration connection between next neighbours regarding the state of enamel.

If $i= m$ and $j=n$ (the last column has been processed), the computation is finished.

After computation by this algorithm values of the linguistic variable of diagnostics for all quads will be calculated. By that the tusk of formation of subsets $X^c$, $X^d$, and $X^h$ is solved. By that the enamel zones with caries, demineralization as well as the healthy zones are determined. The minimum size of a detected zone is $150 \times 150 \mu m^2$. There is no upper limit for a zone size within the matrix size.

On the basis of the described algorithm software was developed for automation of enamel surface diagnostics using MATLAB.

### 3.2 Linguistic rules of diagnostics.

According to the above mentioned 4 code value ranges (and consequently 4 linguistic variable values), as well as the dentistry experts’ answers to the questioner while processing data triplets $4^3 = 64$ linguistic rules are determined. Where «4» stays for 4 evaluations of a quad state that are described above, and «3» stays for 3 close quads. The rules permit to determine a common linguistic variable value (output variable $y$) for zone of 3 quads (input variables $x_1$, $x_2$, and $x_3$). The rules are listed in the table.

<table>
<thead>
<tr>
<th>Combinations of values</th>
<th>$x_1$</th>
<th>$x_2$</th>
<th>$x_3$</th>
<th>$y$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Let us consider an example of application of the linguistic rules for processing a line with the following codes: (0.664; 1.9; 2.91). Fig. 3 shows input evaluation in all linguistic rules. At input 1 the code is 0.664, which explicitly belongs to the caries range. At input 2 the code is 1.9, which belongs to the healthy tissue term with membership function $\mu_{u_2} = 1$. At input 3 the code is 2.91, which belongs to the demineralization term with membership function $\mu_{u_3} = 1$. Evaluation of inputs in all linguistic rules gives output of 3.01, which belongs to the demineralization term and corresponds to the dentist’s experience.

<table>
<thead>
<tr>
<th>$I_1$</th>
<th>$I_2$</th>
<th>$I_3$</th>
<th>$I_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>low</td>
<td>low</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>low</td>
<td>low</td>
<td>high</td>
<td>low</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$I_{44}$</th>
<th>$I_{45}$</th>
<th>$I_{46}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>low</td>
<td>very high</td>
</tr>
<tr>
<td>medium</td>
<td>very high</td>
<td>medium</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$L_{62}$</th>
<th>$I_{63}$</th>
<th>$I_{64}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>very high</td>
<td>low</td>
<td>medium</td>
</tr>
</tbody>
</table>

Figure 3 Evaluation of inputs in all linguistics rules

3.3 Experimental check of the efficiency of the suggested algorithm for processing enamel surface scanning results.

100 teeth were used for experiments. The teeth had been extracted due to therapeutic indications. The procedure of teeth extraction is described in [4]. Among 100 teeth samples used for experiments there were 10 teeth with quite large defects (a dentist could diagnose them visually), 14 teeth with small defects (a dentist could not find them with the unaided eye), the rest of the teeth were healthy [5].

The small defects had been detected with an electron microscope. Most of the teeth (10 out of 14) had demineralization on labial surface in mesial one-third of a tooth. Four teeth had defects on occlusial surface, at that one defect was caused by caries and three by demineralization.

The IONC method showed all the defects that had been found with an electron microscope. It is important to notice that the exact location of small defects is not required because they are treated by preventive measures without surgical intervention.

The results have confirmed that the IONC method and the suggested algorithms for data processing are effective for diagnostics of dental diseases at early stages.

4 Conclusion

A technique for enamel diagnostics is suggested. The technique includes the following: collecting data regarding condition of enamel surface by the method of infrared optical nondestructive control, the data processing on the basis of knowledge collected from expert dentists, MATLAB modeling, and the suggested algorithm for diagnostics. The technique is effective for finding enamel defects from 150µm up that are impossible to detect during visual inspection and that are characteristic for early stages of dental diseases. Thus an effective technique for preventive diagnostics and preventive treatment that does not require enamel destruction has been suggested. The technique’s effectiveness has been confirmed experimentally.

Literature

1. Cortez José I.; Bustillo Díaz M.M., Caldera Miguel J. “Adquisición y procesamiento de datos de la rugosidad de la superficie del esmalte dental utilizando el microcontrolador 8032 “. SOMI XVIII; Congreso de instrumentación 2004.


