Computer-Aided Periodontal Disease Diagnosis using computer vision

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Abstract

Periodontal diseases are the major cause of tooth loss. The evolution of these diseases is crucial to achieve adequate planning and treatment. Depth probing is essential to know the periodontal disease stage. In this paper we present a new system for Computer-Aided Periodontal Disease Diagnosis using computer vision. The system automates the depth probing and incorporates a colour camera fitted together with a plastic probe that automatically and exactly obtains the depth probing measure. The system has been tested by several periodontists and with 125 teeth of different patients. The differences between the values taken by the system and two periodontists have not been significant.

Keywords: automatic depth probing, voice, periodontitis, gingivitis, digital colour image, probe, probe mark, periodontal diseases

1. INTRODUCTION

Periodontal diseases consist of a group of inflammatory diseases initiated by bacteria that colonize the teeth and infect their surrounding soft tissues. The bacteria can affect the gum, bone and other supporting structures of the teeth. Periodontal diseases can be divided into two groups, based on the two stages in which the disease can be, gingivitis and periodontitis. In gingivitis, which is the early stage of periodontal disease, only the soft gum tissue has been affected. At this stage, this disease is still reversible. If not treated, however, it can lead to periodontitis. Periodontitis is the later stage of periodontal disease. The gum, bone, and other structures that support the teeth have been seriously damaged. At this stage, the disease may require extensive treatment or teeth may be lost.

Periodontal diseases are the major cause of tooth loss in adults. If not treated, it can even cause the loss of cavity-free teeth. Some studies have been made in order to determine the severity of this disease. In The United States, a Public Health Service survey (1) of persons aged 18 to 70 years reported that the majority in younger and older age brackets exhibited periodontal disease. Amongst the entire United States population at risk, three out of four people have been diagnosed as having some form of periodontal disease, and about two out of four had active destruction of the supporting tissues around the teeth (marginal periodontitis). After the age of 40, periodontitis is responsible for over 60% of tooth extractions. However, periodontal diseases can occur at any age. Even children as young as five or six can show signs of these diseases. Other similar studies have been carried out in Kenya (2), Sri Lanka (3), Tanzania (4), Ushiku, Japan (5).

The study of the evolution of the disease is one of the most important factors for achieving adequate planning and treatment. In order to know the periodontal disease stage, some methods have been used, such as Radiographic techniques and Probing.

Radiographic techniques that include (6):
- Single and/or dual photon absorptiometry.
- Radiopharmaceutical uptake for analysis of bone metabolism at interdental sites.
- Computerised, digitised subtraction radiography.

The radiographic techniques have several problems such as expense, interpretation of three-dimensional data in a two-dimensional format and risk of the cumulative effect of low dose radiation over time. Moreover, radiographics cannot detect the earliest stage of periodontal disease.

Probing is one of the methods most extensively used in planning and treatment of periodontal diagnosis and moreover in the present paper an automatic method of probing is presented. The paper is organised as follows.
State of art in probing instruments is covered in section two. Section three, materials and methods, includes the description of the digital colour camera used, the steps followed in data acquisition and the algorithm used in depth probing computation. The treatment editor software has been explained in section four. In section five some results obtained have been shown. These sections are followed by a summary.

2. STATE OF THE ART IN PROBING INSTRUMENTS

In depth probing process the periodontist introduces a probe inside the gum and obtains the millimetres of the probe that are inside the gum. A basic definition of a probe is a stick with several marks, that is used for depth probing by periodontists. Probes can be done with different materials, for example plastic or metal, and they can have several marks with different thicknesses. There are several commercial probes. In figure 1 a flexible, plastic and conventional probe can be seen.

![Figure 1. Manual and flexible plastic probe.](image)

This value is taken several times on different dates in order to study its evolution and behaviour. Clinical probing depths have long been used to determine the severity of periodontitis lesions. Despite the limitations in measurement sensitivity of the periodontal probe (7), probing attachment levels obtained with its use have been used as the primary indicator of periodontal status during longitudinal clinical trials.

In order to annotate the depth probing values taken during a manual probing, several techniques can be used: the periodontist can have a nurse that annotates the depth probing values that he dictates; the periodontist can use a recording machine in order to record the data and the nurse can later hear this recording and annotate the data in the clinical data of the patient; or the periodontist can stop taking these values and annotate the data himself. Not all of these techniques are practical. Each one has several disadvantages. Therefore, this manual process is not convenient, making it necessary to automate it.

Periodontists have for years been probing different kinds of probes and methods in order to automate and improve periodontal diagnosis. Numerous investigators have studied how the final measure can affect aspects such as: force with which the probe is inserted (8)(9), probe position, examination experience, etc.. Others have tried to construct different kinds of probes, some of them automatic. Such a probe which incorporates a piezoelectric sensor (10) is subject to inherent drift. Mechanical models (11), (12) employ a variation of conventional leaf springs. There was another type of probe driven by air pressure, but the time necessary to achieve each probing measurement was a clinical encumbrance (13). And an electronic, pressure-sensitive probe (14) has proved to be sensitive, reliable and clinically efficient to use. Gibbs develops Florida probe (15) with electronic measure and controlled pressure.

Other devices based on electronic detection and computer processing information have been developed (16). These instrument are capable of extracting, transmitting and recording diagnostic information. Amongst others, these instruments are:

1) The Interprobe (17) periodontal pocket measurement system measures pocket depth using an optical encoder. The encoder is attached to a disposable plastic probe tip.
2) The Florida probe system (15) measures pocket depth and attachment level. The probe element is metallic and is mechanically connected to a linear displacement transducer.
3) A periodontal probe similar in function to the Florida Probe has been described by researchers at the University of Toronto (18)(19).
4) The Periotest (20) is a hand-held probe for measurement of tooth mobility.
5) The PerioTemp (21) is a thermocouple probe that measures temperature of the periodontal pocket relative to sublingual temperature.

In this paper we present a new system named Computer-Aided Periodontal Disease Diagnosis (CAPDD) that is a complete system for a periodontal hospital. CAPDD has two aspects that make it different in respect to these above-mentioned systems. CAPDD incorporates a colour camera fitted with a conventional plastic probe that takes patient’s digital colour photographs instantaneously and automatically obtains the depth probing measure. CAPDD incorporates voice capabilities that allow the periodontist to only need the system in order to perform his work. When the periodontist sees the right image in the screen he says OK and then the system automatically calculates the mentioned values and displays them on the screen. This system avoids the inconvenience of manual methods such as radiographic techniques. CAPDD automates the depth probing. The probe used is a conventional plastic probe, so it does not have the disadvantages of being heavy or very difficult to handle. The system is also very easy to use. All these advantages makes CAPDD as a system that helps clinicians to perform a correct diagnosis in an easy and automatic way.

3. MATERIAL AND METHODS

3.1 INSTRUMENTATION

The system uses a digital colour camera, model M1050 from JAI (Copenhagen, Denmark), and is composed of the head, the camera control unit (CCU) and a cable. The size and weight of the head and the camera control unit and the cable length are shown in table 1. As it is shown in table 1, the head of the camera is light (as the periodontist has to support it). Therefore the periodontist does not work with heavy equipment. A photograph of this camera can be seen in figure 2.

<table>
<thead>
<tr>
<th>Size and weight of the HEAD</th>
<th>size and weight of the CCU</th>
<th>Cable length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ø 12 x 36 mm / 5,7 g.</td>
<td>110 mm(W) x 40 mm (H) x 154 mm(D) / 550 g.</td>
<td>2 m Ø 3,5</td>
</tr>
</tbody>
</table>

Table 1. The size and weight of the head and the camera control unit and the cable length

The system also uses a conventional plastic probe that can be seen in figure 1. The conventional plastic probe is fitted together with the colour camera using a fixing mechanism that can be seen in figure 3.

The system includes voice capabilities, i.e., the system can work with either voice or in a conventional way. Using voice capabilities the user can manage the system without touching the habitual entry mechanisms, keyboard or mouse. And in this case, it is a very important aspect because the periodontist can use the system without the help of another person who would have to touch the keyboard or mouse in order to manage the
system when he is depth probing. In order to incorporate voice capabilities the VoiceType Developer’s Toolkit (IBM, New York) has been used.

CAPDD uses other special hardware: a FRAME GRABBER (PX510) and a standard microphone.

The implementation of CAPDD has been possible using the development environment VISUAL C++, version 5.0 from Microsoft (Redmond, WA).

### 3.2 DATA ACQUISITION

The most outstanding characteristic of CAPDD is that the system can help periodontists in their day-to-day depth probing calculations.

The data acquisition is achieved when the option of depth probing is selected, in this case an image appears on the screen which captures the camera with the probe in the middle of the image. See an example of this visualisation in figure 4.

![Figure 4: Screen of image capturing.](image)

The process to obtain depth probing is as follows:
1) The periodontist selects the option of depth probing.
2) The periodontist selects the teeth where he can perform depth probing, using one of the possibilities.
3) An image taken by the colour camera at that moment appears on the screen. The user can move the camera and the image focused on by the camera appears on the screen. When the periodontist sees the right image on the screen he says OK. As mentioned above, the system incorporates voice control, that is, it is possible to control the system using the voice.
4) The system calculates the depth probing measure and it appears on the screen.
5) This process is repeated for all teeth.
6) If the periodontist wants to repeat the calculation of a tooth, the system can repeat the process.
7) If the periodontist wants to modify some parameters, he modifies them and later the system repeats the calculation.

To achieve these calculations, the system has to identify teeth, gum and the probe. To be precise, the system has to identify probe marks. As it has been mentioned the probe is fitted together with the camera. And this union results in the probe appearing in a fixed position, generally in the middle of all the images that would be captured. This fixed position can be calibrated. Therefore the system does not have to perform an analysis in the whole image, it would be enough to examine the central area. The system examines only one zone of the image (track zone). If the user does not modify the default values (these values have been empirically determined), the program analyses from the middle of the image, central axis, to 10% of the image wide towards the right side and another 10% of the image wide towards the left side. However the user can select the
position of the central axis and the percentage of the wide image towards the left side and the percentage of the wide image towards the right side that the system has to examine.

The system will perform an accurate calculation if at least one of the probe marks is identified by the system. That means, that at least one probe mark has to be surrounded by a colour other than black in order for the system to identify this mark.

3.3 DEPTH PROBING COMPUTING

The algorithm that computes depth probing consists of the following steps:

1) **Captured Image Transformation.** In order to identify teeth, gum and probe marks, the image has to be transformed. This transformation is achieved by applying thresholding at first. The thresholding is applied twice. Once for black values, the goal in this case being to distinguish probe marks, and another for pink values, now, the goal is to distinguish gum.

2) **Searching of probe marks.** CAPDD tracks the image obtained as a result of step one and searches to find zones where probe marks will probably exist. First, the CAPDD performs a search of 8-connected components. For this search we have developed an efficient algorithm (22). The search of 8-connected components involves to group pixels illuminated that are 8-connected. The algorithm searches the 8-connected components examining rows in pairs. During the search the actual row and its predecessor, if it exists, are examined and a label is assigned to each pixel. An 8-connected component will be composed of pixels that have the same assigned label. The algorithm gives the minimum row and column and the maximum row and column of each 8-connected component. This process is carried out only tracking the image once and its temporal and space complexity are of linear order.

3) **Selecting 8-connected components with probe marks.** The CAPDD has all 8-connected components detected as a result of the second step. But, now the program has to reject the 8-connected components that will probably not contain probe marks. That can be done rejecting all the 8-connected components that have an area greater or lesser than a given one. These values have been empirically determined, but they can be changed using menu options. The system discards the 8-connected components that have a width/height greater or lesser than given values. Moreover, the system rejects the 8-connected components that have too much white to be an 8-connected component with a probe mark. Again these values have been empirically determined, and they can also be changed by the user. So, as a result of this step the selected 8-connected components will probably contain a probe mark.

4) **Selecting the 8-connected component with the right probe mark.** The system stores the real probe marks. Therefore, in this step the system compares stored real probe marks with selected probe marks. As a result of this comparison, the system obtains the correct probe mark. A problem can occur with this step. The greatest probe mark can be partly inside the gum. The system will select that probe mark, but a later exam will detect such circumstance, and the system will select the probe mark above that one.

5) **Calculating depth probing.** Once the right probe mark is selected, the system has to know where the limits of the mark are. The system searches the vertexes of the mark, vertexes c1, c2, c3 and c4 in figure 5. Later, it calculates the middle point between c1 and c2; and c3 and c4, central points. Finally it computes the line equation that passes through these central points. See figure 5.

![Figure 5](image)

**Figure 5.** Points of depth probing calculation.

Later, the system follows the line equation from the centre of the 8-connected component to the end of the visible probe, that is, to the gum. Once this point is found, the system has to compute the real size in millimetres from the centre of the probe mark to the gum. The system knows the size in millimetres of the real probe mark and the number of pixels of the selected probe mark, so it knows the relationship
between them. Moreover, knowing the number of pixels from the centre of the probe mark to the gum makes it easy to calculate the real size in millimetres of the probe outside the gum. Therefore by knowing the real size in millimetres from the centre of the probe mark to the end of the probe, the system can calculate millimetres of the probe inside the gum.

6) **Showing results on the screen.** The system shows the result on the screen. If a problem appears the periodontist can repeat the measure or modify some of the parameters used in the computation of the result. The vertexes of the probe mark and the point that show the end of the probe mark outside the gum can be changed.

7) **Modifying parameters, points and recalculating.** As it has been above-mentioned there are some parameters that can be changed, if the user wants, whether the result not be the right one or the user wants to test the system. Parameters that can be changed: the position of central axis and the percentage of the wide image towards the left side and the percentage of the wide image towards the right side that the system has to examine, the four points of the limits of the probe mark used in calculations and the point where the probe touches the end of the gum, that is, the point that determines the depth probing.

4. **TREATMENT EDITOR SOFTWARE**

In order to perform diagnosis and treatment we have developed software that includes a database where all patient’s data can be stored. X-rays using a scanner or a file, and photographs of a patient’s mouth using the camera, can be incorporated, stored and treated. Data about depth probing can be introduced manually, by voice, or by using the camera. The program also manages plaque and gum index. The program can generate several reports, the standard used by periodontists or a personal one. It is possible to compare photographs taken at different dates, so periodontists can know if the patient is improving or deteriorating in his disease. In the following figures, 6 and 7, several windows of the application can be seen.

![Figure 6. Window with several X-rays.](image-url)
5. RESULTS

The system has been tested by several periodontists and the results have been very satisfactory. Figures 8 to 11 show five examples of depth probing calculations.

Figure 7. Window where teeth can be selected for depth probing

<table>
<thead>
<tr>
<th>Image</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Depth probing = 4.3 mm." /></td>
<td><strong>Figure 8</strong> Depth probing = 4.3 mm.</td>
</tr>
<tr>
<td><img src="image2" alt="Depth probing = 3.59 mm." /></td>
<td><strong>Figure 9</strong> Depth probing = 3.59 mm.</td>
</tr>
</tbody>
</table>
Different patients were treated with the system and with two different periodontists. The number of teeth treated were 125. The position of the probe in all these teeth was in the middle of the tooth, that is, central. The values obtained by the two periodontists were not identical in all cases. In order to test how good the results are we have tested our results with those of the two periodontists.

In order to test if the differences between periodontist values and the system are equal to 0 a differential statistic was applied using the Student’s t-test for independent samples with a significance level of $p<0.05$. In our case, at a significance level of 5% and 124 degree of freedom, the $t$ value is 1.96. The statistical values in this case are shown in table 2.

<table>
<thead>
<tr>
<th>Average dif1</th>
<th>average dif2</th>
<th>variance dif1</th>
<th>variance dif2</th>
<th>$\sqrt{\text{variance dif1}}$</th>
<th>$\sqrt{\text{variance dif2}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.0056</td>
<td>-0.0064</td>
<td>0.00246839</td>
<td>0.00382968</td>
<td>0.04968287</td>
<td>0.06188439</td>
</tr>
</tbody>
</table>

Table 2. Statistical values, where average dif1 shows the average of the differences between the values obtained by the system and periodontist 1, average dif2 shows the average of the differences between the values obtained by the system and periodontist 2, variance dif1 and variance dif2, variances of these differences between values taken by the system and periodontist 1 and 2, respectively. $\sqrt{\text{variance dif1}}$ and $\sqrt{\text{variance dif2}}$ show the square root of variance dif1 and variance dif2, respectively.

We obtain as a result of the differences between the system and periodontist 1 a $t$ value of -1.25.

In this case this result (-1.96≤-1.25514019≤1.96) shows that our hypothesis is acceptable, that is, the difference between the values taken by the system and the values taken by periodontist 1 are not significant.

And the difference between the system and periodontist 2 is -1.15.

In this case this result (-1.96≤-1.15162138≤1.96) also shows that our hypothesis is acceptable, that is, the difference between the values taken by the system and the values taken by periodontist 2 are not significant.

The values taken by the two periodontists are not identical, that means that it is not so easy to determine the right value and in some cases, see the images. We can be sure that the system sometimes obtains the right value and the periodontists do not. Nevertheless, supposing that the periodontists are right, the results obtained show that the system determines the right value in each depth probing. That is, that the system will work in a similar way as a periodontist does.
6. CONCLUSIONS

A new system that automates depth probing for planning and treatment of periodontal diseases has been presented. CAPDD includes a colour camera fitted together with a conventional plastic probe and incorporates voice capabilities. The union of all this make CAPDD an useful tool in periodontists day-to-day work, especially in depth probing.

The system presents several advantages that avoid the inconvenience of manual methods such as radiographic techniques. CAPDD is both very easy to handle and light. The probe is not heavy and easy-to-use, it is a conventional plastic probe. The camera is also light.

The system has been tested by several periodontists and their general opinion has been that the system is a very useful tool for their job. Two of these periodontists have taken depth probing values of 125 teeth from different patients. The differences between the values taken by the system and these two periodontists have not been significant, so CAPDD can work in a similar way to a periodontist.

Moreover, CAPDD has the advantages of whatever database and incorporates capabilities only needed for periodontical treatment. Using the colour camera it is possible to take digital colour photographs during depth probing acquisition that can be seen by periodontists whenever they like, and perform comparisons between them, they can see if the patient is improving or deteriorating in his disease. The system includes voice capabilities, that is, the system can work with voice control or in a conventional way.

In conclusion, CAPDD is an adequate tool for whoever periodontist, especially for planning and treatment of periodontal disease.

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