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Improving Subtraction Radiography via Automated 2D Image Registration

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Abstract

We have developed an initial system for performing 2D image registration for detecting bone density changes in dental radiographs based on aligning automatically extracted stable tooth features. The basic approach is to warp an x-ray image to align its landmark features with an earlier image of the same region to attempt to correct for imaging geometry variations. Although a 3D model is needed to perform truly accurate analysis, they are generally unavailable for these purposes. The goal of this project is to therefore identify the range of geometric variations and bone density changes that can be identified using 2D features and to evaluate the benefits of this approach over the manual change detection techniques currently being used.

Overview

Radiographic diagnosis of periodontal bone loss has long been considered a desirable indicator of periodontal disease status and progression. The aim of such diagnosis is to monitor changes in the alveolar bone, in which the teeth are rooted, via analysis of radiographs taken of the same region of the mouth over time. Changes to be identified consist of both receding bone crests and density changes. Application of radiographic change detection, however, has been hampered by the low sensitivity of manual inspection and the complex image standardization apparatus used for image subtraction [5, 2]. Lacking at this time is a method to achieve registration of radiographs in a reproducible and objective manner to allow accurate subtraction. Current registration methods which attempt to manually line up the images are slow, tedious, and lack reproducibility.

By automating the image registration process, the aim is to better account for variations in position and orientation of the x-ray film and source. Furthermore, with the advent of low dosage digital x-ray sensors, such a technique could provide the clinician fast feedback on repositioning of the sensor, if necessary[3]. Intensity normalization is needed for change detection applications as well, but this problem can usually be solved via calibration step wedges or automatic gain/bias adjustments in known tooth regions. The problem we address in this paper focuses on geometric adjustments only.

Our approach is based on automatic extraction of invariant anatomical structures, such as tooth roots and cementoenamel junctions (CEJ's), points along the tooth edges where the denser tooth enamel is cemented to the tooth dentine. The automatic extraction of these features provides a reliable basis for warping a current radiograph relative to an earlier reference radiograph. We then perform image subtraction to both qualitatively color code bone loss and gain as well as quantitatively assess bone density changes. The automatic extraction of invariant anatomical structures also provides a reference frame for computing relative bone geometry measurements by automating such calculations as CEJ to alveolar crest distances (as is performed manually in [4]). Human interaction is limited to specifying tooth correspondences and verifying results. With this reduced level of interaction, objective and reproducible change detection results are obtained. Furthermore, the use of multiple evidence sources, such as CEJ and tooth edges for registration, and image subtraction and CEJ-bone crest distances for change evaluations should lead

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[3] Since digital sensors are rigid, we can also discount any film warpage once we've calibrated the sensor.

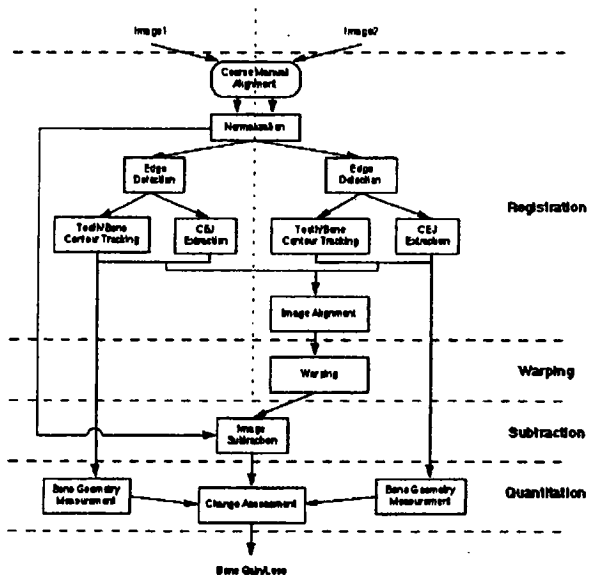

Figure 1: 2D registration and change detection system.

to more reliable results.

Technical Approach

Since we do not have 3D models available for this task, we make several simplifying assumptions:

- Teeth can be approximated as cylinders so minimal geometrical shape variations are introduced on the vertical edges of the teeth for small viewpoint variations.
- The registration is based on invariant point features on the teeth, preferably on both sides of the bone crest region, such as CEJ's and root tips. Since these features are close to the vertical bisecting plane of the teeth, the locations of these point features in the image will generally correspond to the same physical location on the teeth under the expected ranges of viewing variations.
- Using orthographic projection, the viewing variations can be corrected via a linear transformation. We perform a bilinear warping to also account for some distortion in the film as well.

The system diagram for the this system is shown in Figure 1. The processing is designed to be automatic after initial coarse manual alignment which labels the teeth to produce tooth correspondences. We used a Canny edge detector [1] for extracting tooth and bone edge points, which are linked together based on their proximity. Small gaps are filled by interpolation. CEJ extraction is then performed by matching a CEJ model along identified vertical tooth edges. The CEJ model represents the two neighboring enamel and dentine regions via Δ's in the means and standard deviations of the regions as well as the angle between the interface boundary and the tooth edge. The extracted CEJ's and tooth boundaries are then used to align the two images. Given the initial coarse manual image alignment, we use the edge contour gradient direction to match corresponding CEJ's and tooth edges from the two images. Based on the point correspondences we compute the least-squares bilinear warping coefficients and warp one of the images relative to the other. It is at this point that decisions could be made on whether the desired warping is too drastic, thus requiring user verification or re-imaging. Bone gain/loss and density change assessment can then made by subtracting the two images and measuring changes in the CEJ-alveolar crest distances.

We have currently implemented edge detection, contour tracking, preliminary CEJ extraction, bilinear image warping, and image subtraction modules [3].

Results

As a test case we used radiographs taken of a patient treated by Widman flap surgery, made available to us by the Forsyth Dental Center, Boston MA. The first radiograph was taken prior to surgery and the second taken six months after surgery. These were film radiographs which we digitized at 600 dpi on a ColorGetter+ drum scanner[4]. A corresponding image pair from this patient is shown in the top of Figure 2. Note that although manual efforts were taken to geometrically standardize these images, the configuration of overlapping teeth differs in the two images indicating the need for some warping to accurately register the two images.

Preliminary results of automatic extraction of CEJ's are shown in the lower left of Figure 2. Candidate CEJ's are shown as white circles. The brightness of the original images has been decreased to make the dots apparent. These preliminary tests indicate that accurate automated localization of CEJ's is feasible with these images. Although several false candidate CEJ locations were generated, they could be removed from consideration based on knowledge of general teeth location. Although desirable, not all CEJ points are necessary for performing the image registration. Rather, we need to have sufficient coverage of alignment points across both images.

As an example of how the extracted CEJ points can be used, we identified the correspondences of

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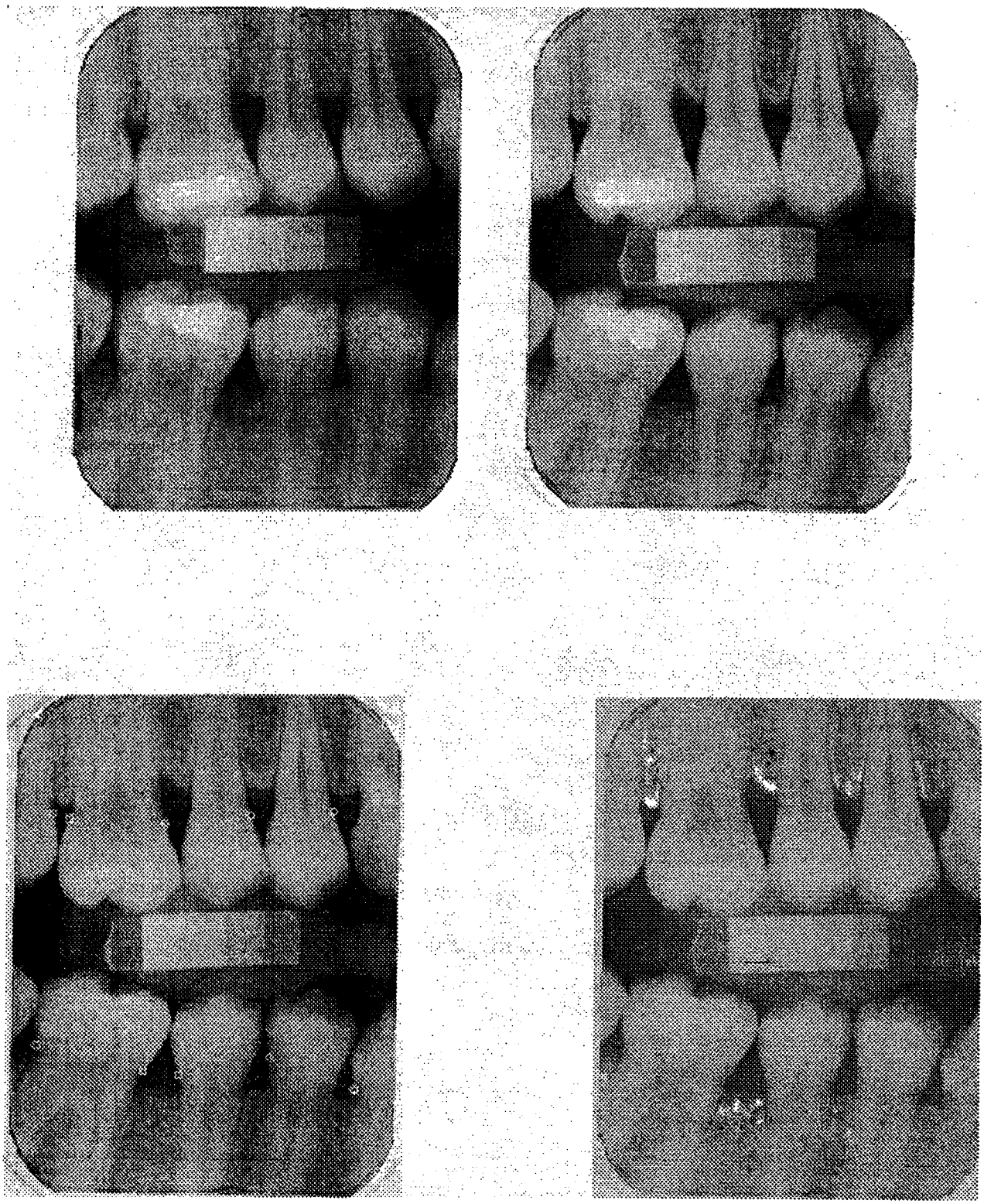

Figure 2: Original reference radiograph (top left) and corresponding radiograph taken six months later (top right). Candidate CEJ's extracted in second radiograph (bottom left) and resulting changes after warping (bottom right).

the automatically extracted CEJ's as a basis for aligning and warping one the images relative to the other. In lieu of tooth root tips, we manually specified additional correspondence points to achieve adequate coverage of alignment points across the images.

Areas of significant change were then highlighted in the subtracted image to indicate bone loss and gain. These results are shown in the bottom right of Figure 2 where bone loss is shown in black and gain in white overlaid on the reduced contrast original radiograph. By visual comparison with the original radiographic images, it can be noted that these results highlight areas of apparent bone regeneration and increased bone density in several interproximal regions. On first inspection of the radiographs it may have not been clear whether the changes are due to bone gain or loss. In this particular case, little bone loss is evident.

Conclusion

The need for accurate and reproducible alveolar bone change detection suggests a reliable automated procedure for accomplishing this task. We are exploring a promising approach based on invariant anatomical structures that overcome some of the problems in performing subtraction radiography caused by viewing geometry variations. Further studies are necessary to determine the levels of reproducibility and sensitivity of this approach.

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