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Date of Application: 27/Jun/2002
Grantee : THIAGARAJAR COLLEGE OF ENGINEERING
Patentee (current assignee) : THIAGARAJAR COLLEGE OF ENGINEERING

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Detail	
APPLICATION NUMBER	916/CHE/2015
APPLICANT NAME	**THIAGARAJAR COLLEGE OF ENGINEERING**
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To,
Dr. R. VASUDEVAN

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Sr. No.	CBR No.	Reference Number /Application Type	Application Number	Title/Remarks	Amount Paid
1	13730	E-17(xiii)/9684/2016-CHE	198254	---	26400
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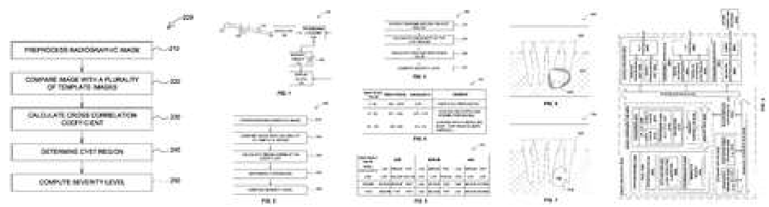
Dental cysts detector

Abstract

A system and method for detecting a cyst from a dental radiographic image is provided. The system and method comprises comparing the radiographic image to a plurality of template images, calculating a cross correlation coefficient between a plurality of regions in the radiographic image and a corresponding plurality of regions in the template image, determining a cyst region in the radiographic image based on a value of the cross correlation coefficient and computing a severity level of the cyst.

Images (5)



Classifications

A61B6/14 Applications or adaptations for dentistry

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Claims (24)

The invention claimed is:

1. A method for detecting an abnormality from a radiographic image, the method comprising:

comparing, at a processing system, data representative of the radiographic image to reference template image data;

calculating, at the processing system, a cross correlation coefficient between a plurality of regions in the data representative of the radiographic image and a corresponding plurality of regions in the reference template image data;

determining, at the processing system, an abnormality region in the data representative of the radiographic image based on a value of the cross correlation coefficient; and

computing, at the processing system, a severity level of the abnormality region.

2. The method of claim 1, wherein the determining the abnormality region comprises using an artificial neural network with a radial basis function.

3. The method of claim 1, wherein the severity level is computed based on at least one of an area of the abnormality region, a gray scale value of the abnormality region, and a circularity of the abnormality region.

4. The method of claim 1, further comprising preprocessing the data representative of the radiographic image prior to comparing the data representative of the radiographic image with the reference template image data.

5. The method of claim 1, wherein the radiographic image comprises a dental image, and wherein the abnormality region comprises a cyst.

6. The method of claim 1, wherein the reference template image data is derived from at least five template images.

7. The method of claim 1, further comprising normalizing the cross correlation coefficient for each region in the data representative of the radiographic image and converting the cross correlation coefficient to a gray scale value.

8. The method of claim 1, wherein each region of the plurality of regions in the data representative of the radiographic image comprises one pixel.

9. The method of claim 1, wherein the abnormality region is the region in the data representative of the radiographic image with a highest value of the cross correlation coefficient.

10. A method for dental cyst diagnosis, the method comprising:

comparing, at a processing system, data representative of a dental image to reference template image data;

calculating, at the processing system, a cross correlation coefficient between the data representative of the dental image and the reference template image data;

determining, at the processing system, a cyst region in the data representative of the dental image that comprises a cyst based on the cross correlation coefficient; and

computing, at the processing system, severity level of the cyst.

11. The method of claim 10, wherein the determining the cyst region comprises using an artificial neural network with a radial basis function.

12. The method of claim 10, wherein the severity level is computed based on at least one of an area of the cyst region, a gray scale value of the cyst region, and a circularity of the cyst region.

13. The method of claim 10, further comprising preprocessing the data representative of the dental image using contrast stretching prior to comparing the data representative of the dental image to the reference template image data.

14. A system for detecting a cyst from a radiographic image, the system comprising:

a memory circuit; and

template image processing circuitry coupled to the memory circuit and configured to:

compare data representative of the radiographic image to reference template image data;

calculate a cross correlation coefficient between a plurality of regions in the data representative of the radiographic image and a corresponding plurality of regions in the reference template image data;

determine a cyst region in the data representative of the radiographic image that comprises the cyst based on a value of the cross correlation coefficient, and

compute a severity level of the cyst.

15. The system of claim 14, wherein the template image processing circuitry is configured to detect the cyst region using an artificial neural network with a radial basis function.

16. The system of claim 14, wherein the severity level is computed based on at least one of an area of the cyst region, a gray scale value of the cyst regio and a circularity of the cyst region.

17. The system of claim 14, wherein the template image processing circuitry is configured to preprocess the data representative of the radiographic image prior to comparing the data representative of the radiographic image with the reference template image data.

18. The system of claim 14, wherein the template image processing circuitry is configured to compare data representative of the radiographic image to reference template image data derived from at least five template images.

19. The system of claim 14, wherein the template image processing circuitry is configured to normalize the cross correlation coefficient for each region in the data representative of the radiographic image and convert the cross correlation coefficient to a gray scale value.

20. The system of claim 14, wherein the cyst region corresponds to a region in the data representative of the radiographic image with a highest value of the cross correlation coefficient.

21. The method of claim 1, wherein the computing a severity level of the abnormality region comprises assigning a relative severity value corresponding to the severity level of the abnormality region, and wherein the relative severity value is indicative of a condition of an abnormality depicted in the abnormality region.

22. The method of claim 1, wherein the severity level is computed based on an area of the abnormality region, a gray scale value of the abnormality region, and a circularity of the abnormality region.

23. The method of claim 1, wherein the computing a severity level of the abnormality region is performed after a determination of the existence of the abnormality region.

24. The method of claim 1, wherein the computing a severity level of the abnormality region is separate from a determination of the existence of the abnormality region.

Description

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to Indian Patent Application Serial No. 2759/CHE/2009 filed Nov. 11, 2009, the contents of which are incorporated by reference herein in its entirety.

BACKGROUND

One of the most common dental pathologies is dental cysts. Cysts generally occur more often in the jaws than in any other bone. Usually they are round or oval in shape, resembling a fluid filled balloon. Cysts are normally radiolucent and grow slowly, and can sometimes causing displacement and resorption of the teeth. Clinically dental related cysts appear fluctuant inside the mouth.

Typically, detection of dental pathologies is performed by a dentist during a clinical examination of a patient. Sometimes extra oral swelling may be seen depending upon the nature and the extent of the cyst. By aspirating the fluid with a syringe inserted into the swelling, the dentist can roughly diagnose the cyst. However, the exact extension and number of teeth involved in the cystic region cannot be accurately determined.

In recent applications, dental diagnostic imaging methods are employed in confirming the presence and the extent of cysts, tumors, etc. in the oral cavity. Dental imaging techniques include magnetic resonance imaging (MRI), computed tomography (CT), ultrasound (US), and intra-oral and extra-oral radiography. It has been observed that dental radiographs greatly assist in the identification and evaluation of oral pathologies like dental cysts, tumor and cancer.

However, the image processing-based detection techniques currently employed are not automated, and diagnosis is generally performed by manually examining the radiographic image of the oral cavity. Therefore, detection using such techniques is usually subjective and may vary in accuracy due to factors such as viewing conditions and dentist expertise, among others. In addition, such techniques are not adequate to determine a severity level of the detected cysts.

SUMMARY

Briefly according to one embodiment of the present technique, a method for detecting an abnormality from a radiographic image is provided. The method comprises comparing data representative of the radiographic image to a plurality of template image data, calculating a cross correlation coefficient between a plurality of regions in the radiographic image data and a corresponding plurality of regions in the template image data, determining an abnormality region in the radiographic image data based on a value of the cross correlation coefficient, and computing a severity level of the abnormality.

In another embodiment, a method for dental cyst diagnosis is provided. The method comprises comparing data representative of a dental image to reference template image data, calculating a cross correlation coefficient for the image data and each template image data, determining a cyst region in the image data that comprises the cyst based on the cross correlation coefficient and computing a severity level of the cyst.

In another embodiment, a system for detecting a cyst from a radiographic image is provided. The system comprises memory circuit configured to store a plurality of template images. The system further includes image processing circuitry coupled to the memory circuit and configured to compare the radiographic image to a plurality of template images, to calculate a cross correlation coefficient between a plurality of regions in the radiographic image and a corresponding plurality of regions in the template image, to determine a cyst region in the radiographic image that comprises the cyst based on a value of the cross correlation coefficient, and to compute a severity level of the cyst.

The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 is a diagrammatical representation of an example imaging system for detecting cysts from a dental radiographic images;

FIG. 2 is a flow chart illustrating one technique by which a cyst is determined from a dental radiographic image;

FIG. 3 is a flow chart illustrating one technique by which a severity level of a cyst is determined;

FIG. 4 is a table depicting severity levels based on example values of circularity, area and gray scale values;

FIG. 5 is a table depicting severity levels for different values of the input parameters;

FIG. 6 is an example of a dental radiographic image;

FIG. 7 is an example of a processed dental radiographic image that depicts the dental cyst; and

FIG. 8 is a block diagram of an embodiment of a computing device that may be used to implement the present techniques.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented herein. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the Figures, can be arranged, substituted, combined, separated, and designed in a wide variety of different configurations, all of which are explicitly contemplated herein.

Example embodiments are generally directed to detection of dental cysts. The technique provides an automated diagnostic system that processes radiographic images of the oral cavity and detects dental cysts using image processing techniques, as will be described in detail below.

Referring now to FIG. 1, an example imaging system **100** for detecting cysts inside the mouth of a subject is illustrated. As used herein, the term “cyst” refers round or oval shaped closed sacs that occur more often in the jaws. As illustrated, the system **100** includes a radiation source **110**, a detector **120**, processing circuitry **130**, memory circuit **140** and display device **160**. Each block is described in further detail below.

Radiation source **110** is configured to transmit radiation **112** in the direction through an identified region of interest around the mouth **105**. In one embodiment, the radiation source is an X-ray source. Detector **120** receives the radiation that passes through the region of interest and converts to corresponding lower energy photons, and subsequently to digital data.

Processing circuitry **130** is configured to suitably process the data collected from the detector **120** and generate an image of the region of interest. The image of the scanned region of interest is displayed on display device **160** or may be stored in memory circuit **140**. Processing circuitry is configured to further analyze the image to detect a presence of cyst.

Memory circuit **140** is configured to store a plurality of template images **150**. In one embodiment, the radiographic image generated by the processing circuitry **130** is also stored in memory circuit **140**. As will be understood in those skilled in the art, although a single memory circuit is described here by way of example, the functions performed by the memory circuit may consist of more than one memory device associated with the system for storing radiographic images, template images and so forth.

The memory circuit **140** may include hard disk drives, optical drives, tape drives, random access memory (RAM), read-only memory (ROM), programmable read-only memory (PROM), redundant arrays of independent disks (RAID), flash memory, magneto-optical memory, holographic memory, bubble memory, magnetic drum, memory stick, Mylar® tape, smartdisk, thin film memory, zip drive, and so forth.

As discussed above, the processing circuitry is configured to process and analyze the radiographic image to detect cysts. The manner in which a cyst is detected from a radiographic image is described in further detail below with reference to FIG. 2.

FIG. 2 is a flow chart depicting one method to detect cysts from a dental radiographic image. In one embodiment, the steps of the process **200** described below are performed by processing circuitry of the imaging system as shown in FIG. 1. Each step is described in further detail below. At step **210**, the radiographic image is preprocessed. In one embodiment, a contrast stretching algorithm is applied on the image to enhance the edges of various structures within the image. Structures within the image may include teeth, jaw bone, cysts, etc.

At step **220**, the radiographic image is compared to a plurality of template images. As used herein, a template image is a reference image of a typical dental cyst. In one embodiment, the radiographic image is compared to at least five template images. It should be appreciated that, while reference is made in the present discussion to “images”, in the actual processing, image data (i.e., data representing features of the teeth, jaw bone, cysts, etc.) is used in processing, comparisons, diagnosis, and so forth. For simplicity, however, such data is referred to as the image itself, although the image data may or may not be used to produce an actual image. Similarly, while reference is made to a “template” image, this “image” may consist of data that is combined for a reference set, such as to arrive at values that are indicative of features sought or detectable in the image under consideration.

At step **230**, a cross correlation coefficient is calculated between a plurality of regions in the radiographic image and a corresponding plurality of regions in the template image. In one embodiment, each plurality of regions includes one pixel. In one embodiment, the cross correlation coefficient $\gamma(s, t)$ is normalized and is computed using the following equation:

$$\gamma(s,t) = \frac{\sum_x \sum_y [f(x,y) - \bar{f}(x,y)][w(x-s,y-t) - \bar{w}]}{\left\{\sum_x \sum_y [f(x,y) - \bar{f}(x,y)]^2 \sum_x \sum_y [w(x-s,y-t) - \bar{w}]^2\right\}^{\frac{1}{2}}} \quad \text{Equation (1)}$$

where s=0, 1, 2, . . . , M−1, t=0, 1, 2, . . . , N−1, w is the average value of the pixel in w(x,y), f(x, y) is the average value of f(x, y) in the region coincident with the current location of w, and the summations are taken over the coordinates common to both w and f.

At step **240**, a cyst region is identified (if present) in the radiographic image based on a value of the cross correlation coefficient. In one embodiment, a high value of the cross correlation coefficient indicates a presence of a cyst. In one embodiment the normalized cross correlation coefficients determined using equation (1) are converted to corresponding gray scale values and are referred to generally as expanded normalized cross correlation coefficients (ENCC). In a specific embodiment, the ENCC values vary from 0 to 255.

In one embodiment, artificial neural networks with radial basis functions are used to categorize regions in the radiographic image based on the ENCC values. In one embodiment, the regions are categorized as highly suspicious, suspicious, slightly suspicious and not suspicious. At step **250**, a severity level of the cyst is computed. The manner in which the severity level of the cyst is computed is described in further detail below.

FIG. 3 is a flow chart depicting one method to determine a severity level of a cyst detected in a dental radiographic image. As described in the flow chart of FIG. 2, a cyst region is identified in the dental radiographic image based on a value of the cross correlation coefficients. The severity level of the cyst is determined as described in the following steps of process **300**. At step **310**, regions surrounding the identified cyst regions are extracted. In one embodiment, the regions are extracted using the connectivity property. At step **320**, a circularity of the cyst region is calculated. In one embodiment, the circularity is calculated by comparing an area of a region inside an equivalent circle with the area of the cyst region. At step **330**, a gray scale value and an area of the cyst region is calculated based on the circularity of the cyst region. In one embodiment, the gray scale value and the area is calculated when the calculated circularity exceed a threshold value. At step **340**, a severity level is computed for the cyst region based on the circularity, the area and the gray scale value.

FIG. 4 is a table illustrating severity levels for corresponding values of circularity, area and gray scale values. For example, for a circularity ranging from 0.75-1, area of the cyst region between 1001-3000 pixels and a gray scale value that ranges from 0-40, the cyst is completely perforated. Similarly for a circularity ranging of 0.61-0.75 of the cyst region between 251 and 1000 pixels and a gray scale value that ranges from 41-60, indicates that the cyst involves one cortex and has begun perforating. For a circularity ranging of 0.5-0.6 of the cyst region between 200 and 251 pixels and a gray scale value that ranges from 61-150, indicates that the cyst is confined within the medullary bone.

In one embodiment, fuzzy logic technique is used to compute the severity level as shown in FIG. 5. FIG. 5 is a table showing severity levels computed based on input parameters using a fuzzy logic technique. Each input parameter namely circularity of the cyst region, the area and the gray scale values is marked by a high, medium or low level. Similarly, the output of the fuzzy logic technique which is indicative of the severity level of the cyst is also given a high, medium or low rating based on the combination of the input parameters. In one embodiment, a low severity level indicates that the cyst region is confined within the medullary bone. A medium severity level indicates that the cyst has begun perforating and a high severity level indicates a completely perforated.

The techniques described above assist in the accurate detection of dental cysts from a dental radiographic image. FIG. 6 is an example dental radiograph image **600** comprising a plurality of features such as teeth **610**, tissue **620** and potential cyst region **630**. Upon application of the techniques described herein accurate detection and severity level of dental cysts are determined from the dental radiographic image.

FIG. 7 is an example of a processed dental radiographic image **700** in which a boundary **710** of the cyst region **720** has been clearly identified. Based on the area of the identified cyst region, a gray scale value of the cyst region and a circularity of the cyst region, a severity level of the cyst is computed as described in the flow chart of FIG. 3.

In an embodiment applying the above described techniques provide accurate detection of a cyst from the dental radiographic image. In addition, by employing fuzzy logic techniques, a severity level of the cyst is also determined by comparing parameters such as the area of the cyst region, a gray scale value and the circularity of the cyst region. The technique assists dentists to accurately diagnose and determine a corresponding treatment plan.

FIG. 8 is a block diagram illustrating an example computing device **800** that is arranged for detecting cysts from a dental radiographic image in accordance with the present disclosure. In a very basic configuration **802**, computing device **800** typically includes one or more processors **804** and a system memory **806**. A memory bus **808** may be used for communicating between processor **804** and system memory **806**.

Depending on the desired configuration, processor **804** may be of any type including but not limited to a microprocessor (μP), a microcontroller (μC), a digital signal processor (DSP), or any combination thereof. Processor **804** may include one more levels of caching, such as a level one cache **810** and a level two cache **812**, a processor core **814**, and registers **816**. An example processor core **814** may include an arithmetic logic unit (ALU), a floating point unit (FPU), a digital signal processing core (DSP Core), or any combination thereof. An example memory controller **818** may also be used with processor **804**, or in some implementations memory controller **818** may be an internal part of processor **804**.

Depending on the desired configuration, system memory **806** may be of any type including but not limited to volatile memory (such as RAM), non-volatile memory (such as ROM, flash memory, etc.) or any combination thereof. System memory **806** may include an operating system **820**, one or more applications **822**, and program data **824**. Application **822** may include a cyst detection algorithm **826** that is arranged to the functions as described herein including those described with respect to process **200** of FIG. 2 and process **300** of FIG. 3. Program Data **824** may include template images **828** that may be useful for comparing with the radiographic image as will be further described below. In some embodiments, application **822** may be arranged to operate with program data **824** on operating system **820** such that cyst are detected from dental radiographic images as described herein. This described basic configuration **802** is illustrated in FIG. 8 by those components within the inner dashed line.

Computing device **800** may have additional features or functionality, and additional interfaces to facilitate communications between basic configuration **802** and any required devices and interfaces. For example, a bus/interface controller **830** may be used to facilitate communications between basic configuration **802** and one or more data storage devices **832** via a storage interface bus **834**. Data storage devices **832** may be removable storage devices **836**, non-removable storage devices **838**, or a combination thereof. Examples of removable storage and non-removable storage devices include magnetic disk devices such as flexible disk drives and hard-disk drives (HDD), optical disk drives such as compact disk (CD) drives or digital versatile disk (DVD) drives, solid state drives (SSD), and tape drives to name a few. Example computer storage media may include volatile and nonvolatile, removable and non-removable media implemented in any method or technology for storage of information, such as computer readable instructions, data structures, program modules, or other data.

System memory **806**, removable storage devices **836** and non-removable storage devices **838** are examples of computer storage media. Computer storage media includes, but is not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which may be used to store the desired information and which may be accessed by computing device **800**. Any such computer storage media may be part of computing device **800**.

Computing device **800** may also include an interface bus **840** for facilitating communication from various interface devices (e.g., output devices **842**, peripheral interfaces **844**, and communication devices **846**) to basic configuration **802** via bus/interface controller **830**. Example output devices **842** include a graphics processing unit **848** and an audio processing unit **850**, which may be configured to communicate to various external devices such as a display or speakers via one or more A/V ports **852**. Example peripheral interfaces **844** include a serial interface controller **854** or a parallel interface controller **856**, which may be configured to communicate with external devices such as input devices (e.g., keyboard, mouse, pen, voice input device, touch input device, etc.) or other peripheral devices (e.g., printer, scanner, etc.) via one or more I/O ports **858**. An example communication device **846** includes a network controller **860**, which may be arranged to facilitate communications with one or more other computing devices **862** over a network communication link via one or more communication ports **864**.

The network communication link may be one example of a communication media. Communication media may typically be embodied by computer readable instructions, data structures, program modules, or other data in a modulated data signal, such as a carrier wave or other transport mechanism, and may include any information delivery media. A “modulated data signal” may be a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media may include wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, radio frequency (RF), microwave, infrared (IR) and other wireless media. The term computer readable media as used herein may include both storage media and communication media.

Computing device **800** may be implemented as a portion of a small-form factor portable (or mobile) electronic device such as a cell phone, a personal data assistant (PDA), a personal media player device, a wireless web-watch device, a personal headset device, an application specific device, or a hybrid device that include any of the above functions. Computing device **800** may also be implemented as a personal computer including both laptop computer and non-laptop computer configurations.

The present disclosure is not to be limited in terms of the particular embodiments described in this application, which are intended as illustrations of various aspects. Many modifications and variations can be made without departing from its spirit and scope, as will be apparent to those skilled in the art. Functionally equivalent methods and apparatuses within the scope of the disclosure, in addition to those enumerated herein, will be apparent to those skilled in the art from the foregoing descriptions. Such modifications and variations are intended to fall within the scope of the appended claims. The present disclosure is to be limited only by the terms of the appended claims, along with the full scope of equivalents to which such claims are entitled. It is to be understood that this disclosure is not limited to particular methods, reagents, compounds compositions or biological systems, which can, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity.

It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as “open” terms (e.g., the term “including” should be interpreted as “including but not limited to,” the term “having” should be interpreted as “having at least,” the term “includes” should be interpreted as “includes but is not limited to,” etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases “at least one” and “one or more” to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles “a” or “an” limits any particular claim containing such introduced claim recitation to embodiments containing only one such recitation, even when the same claim includes the introductory phrases “one or more” or “at least one” and indefinite articles such as “a” or “an” (e.g., “a” and/or “an” should be interpreted to mean “at least one” or “one or more”); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should be interpreted to mean at least the recited number (e.g., the bare recitation of “two recitations,” without other modifiers, means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to “at least one of A, B, and C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “a system having at least one of A, B, and C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to “at least one of A, B, or C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “a system having at least one of A, B, or C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms. For example, the phrase “A or B” will be understood to include the possibilities of “A” or “B” or “A and B.”

In addition, where features or aspects of the disclosure are described in terms of Markush groups, those skilled in the art will recognize that the disclosure is also thereby described in terms of any individual member or subgroup of members of the Markush group.

As will be understood by one skilled in the art, for any and all purposes, such as in terms of providing a written description, all ranges disclosed herein also encompass any and all possible subranges and combinations of subranges thereof. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, tenths, etc. As a non-limiting example, each range discussed herein can be readily broken down into a lower third, middle third and upper third, etc. As will also be understood by one skilled in the art all language such as “up to,” “at least,” “greater than,” “less than,” and the like include the number recited and refer to ranges which can be subsequently broken down into subranges as discussed above. Finally, as will be understood by one skilled in the art, a range includes each individual member. Thus, for example, a group having 1-3 cells refers to groups having 1, 2, or 3 cells. Similarly, a group having 1-5 cells refers to groups having 1, 2, 3, 4, or 5 cells, and so forth.

While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

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Family To Family Citations				

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Publication number	Priority date	Publication date	Assignee	Title
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Family To Family Citations				

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JP2007524438A	2007-08-30	The method of compensation in the radiation image processing techniques
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Priority And Related Applications

Priority Applications (2)

Application	Priority date	Filing date	Title
IN2759/CHE/2009		2009-11-11	
IN2759CH2009		2009-11-11	

Applications Claiming Priority (1)

Application	Filing date	Title
PCT/IB2010/054344	2010-09-27	Dental cysts detector

Legal Events

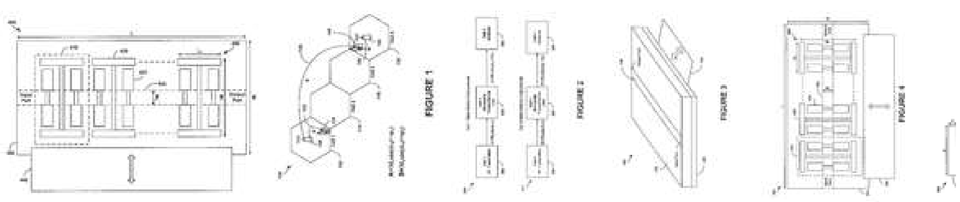
Date	Code	Title	Description
2009-12-30	AS	Assignment	**Owner name**: THIAGARAJAR COLLEGE OF ENGINEERING, INDIA **Free format text**: ASSIGNMENT OF ASSIGNORS INTEREST;ASSIGNORS:BANUMATHI, A.;RAJU, S.;ABHAIKUMAR, V.;REEL/FRAME:023719/0540 **Effective date**: 20091215
2015-09-15	CC	Certificate of correction	

Devices and methods for phase shifting a radio frequency (RF) signal for a base station antenna

Abstract

Methods and devices for phase shifting an RF signal for a base station antenna are provided. The device includes a transmission line that has a stationary ground plane coupled to the top of a substrate and a signal line on the bottom of the substrate. The signal line has an input port and an output port. The input port receives the RF signal with a certain phase and travels across the bottom of the substrate to the output port. The RF signal has a different phase at the output port because defected ground structures etched on the stationary ground plane shift the phase of the RF signal. In addition, the device includes a movable ground plane that may cover a portion of the defected ground structures, the substrate, and the stationary ground plane such that the moveable ground plane further adjusts the phase of the RF signal.

Images (10)



Classifications

H01P1/184 Strip line phase-shifters

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US8862063B2

US Grant

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Priority date : 2010-01-28

Family: US (3)

Date	App/Pub Number	Status
2010	US12723161	Abandoned
2012-12-10	**US13710346**	**Active**
2013-04-25	US20130099877A1	Application
2014-10-14	**US8862063B2**	**Grant**
2012	US13710330	Active

Info: Patent citations (8), Non-patent citations (12), Cited by (4), Legal events, Similar documents, Priority and Related Applications

External links: USPTO, USPTO Assignment, Espacenet, Global Dossier, Discuss

Claims (17)

What is claimed is:

1. An apparatus comprising:

a substrate comprising a signal line;

a first defected ground structure and a second defected ground structure printed onto the substrate to form a first ground plane,

wherein the first and second defected ground structures are configured to shift a phase of an RF signal,

wherein the first defected ground structure includes a short stem dumbbell structure and the second defected ground structure includes a long stem dumbbell structure, and

wherein the first defected ground structure is nested within the second defected ground structure;

a user interface configured to receive dimensions of the first and second defected ground structures, a target beam tilt value for a base station antenna, and a target phase shift; and

a second ground plane configured to removably and selectively cover a portion of at least one of the first and second defected ground structures, thereby adjusting the phase shift of the RF signal, and the adjusting being based at least in part on the received dimensions, target beam tilt value, and target phase shift.

2. The apparatus of claim 1, further comprising:

a plurality of defected ground structures, the plurality of defected ground structures including the first and second defected ground structures; and

wherein the second ground plane is configured to removably and selectively cover the plurality of defected ground structures, thereby adjusting the phase shift of the RF signal.

3. The apparatus of claim 2, further comprising a stepper motor configured to slide the second ground plane a target distance.

4. The apparatus of claim 3, further comprising a microcontroller configured to control an amount of rotation of the stepper motor to slide the second ground plane the target distance.

5. The apparatus of claim 1, further comprising an RF transmitter to modulate the RF signal at an operating frequency.

6. The apparatus of claim 1, wherein the first defected ground structure further comprises at least one of a rectangular, triangular, dumbbell, and circular defected ground structure and the second defected ground structure further comprises at least one of the rectangular, triangular, dumbbell, and circular defected ground structure.

7. A method comprising:

receiving an RF signal having a first phase at an input port of a signal line;

transmitting the RF signal across the signal line to an output port;

shifting a phase of the RF signal from a first phase at the input port to a second phase at the output port using a substrate including the signal line and a first defected ground structure and a second defected ground structure printed on the substrate to form a first ground plane,

wherein the first defected ground structure includes a short stem dumbbell structure and the second defected ground structure includes a long stem dumbbell structure, and

wherein the first defected ground structure is nested within the second defected ground structure;

receiving dimensions of the first and second defected ground structures, a target beam tilt value for a base station antenna, and a target phase shift; and adjusting the phase shift of the RF signal, based at least in part on the received dimensions, target beam tilt value, and a target phase shift, by removably and selectively covering a portion of at least one of the first and second defected ground structures by a second ground plane.

8. The method of claim 7, wherein an RF transmitter modulates the RF signal at an operating frequency.

9. The method of claim 7, wherein the first defected ground structure comprises at least one of a rectangular, triangular, dumbbell, and circular defected ground structure and the second defected ground structure further comprises at least one of the rectangular, triangular, dumbbell, and circular defected ground structure.

10. The method of claim 7, further comprising calculating the target phase shift based on the target mean tilt value and the dimensions of the first and second defected ground structures.

11. The method of claim 7, further comprising determining a target distance to slide the second ground plane to cover a portion of at least one of the first and second defected ground structures to achieve the target phase shift.

12. The method of claim 11, further comprising sending instructions to a microcontroller to rotate a stepper motor an amount that allows the stepper motor to slide the second ground plane the target distance.

13. A non-transitory computer-readable medium having stored thereon, computer-executable instructions that, in response to execution by an apparatus, cause the apparatus to perform functions comprising:

receiving an RF signal having a first phase at an input port of a signal line;

transmitting the RF signal across the signal line to an output port;

shifting a phase of the RF signal from a first phase at the input port to a second phase at the output port using a substrate including the signal line and a first defected ground structure and a second defected ground structure printed onto the substrate to form a first ground plane,

wherein the first defected ground structure includes a short stem dumbbell structure and the second defected ground structure includes a long stem dumbbell structure, and

wherein the first defected ground structure is nested within the second defected ground structure;

receiving dimensions of the first and second defected ground structures, a target beam tilt value for a base station antenna, and a target phase shift; and

adjusting the phase shift of the RF signal, based at least in part on the received dimensions, target beam tilt value, and a target phase shift, by removably and selectively covering a portion of at least one of the first and second defected ground structures by a second ground plane.

14. The non-transitory computer-readable medium of claim 13, wherein the functions further comprise determining a target distance to slide the second ground plane to cover a portion of at least one of the first and second defected ground structures to achieve the target phase shift.

15. The non-transitory computer-readable medium of claim 14, wherein the functions further comprise sending instructions to a microcontroller to rotate a stepper motor an amount that allows the stepper motor to slide the second ground plane the target distance.

16. The non-transitory computer-readable medium of claim 13, wherein the functions further comprise modulating the RF signal at an operating frequency.

17. The non-transitory computer-readable medium of claim 13, wherein the first defected ground structure further comprises at least one of a rectangular, triangular, dumbbell, and circular defected ground structure and the second defected ground structure further comprises at least one of the rectangular, triangular, dumbbell, and circular defected ground structure.

Description

CROSS-REFERENCE TO RELATED APPLICATION

The present application is a Continuation of U.S. Ser. No. 12/723,161, filed Mar. 12, 2010, which claims priority under 35 U.S.C. §119 to a corresponding patent application filed in India and having application number 222/CHE/2010, filed on Jan. 28, 2010, the entire contents of which are herein incorporated by reference.

BACKGROUND

Cellular networks have limited capacity for transmitting and receiving voice calls and electronic data (e.g., text messages, multimedia messages, email, web browsing, etc.) between base stations and cellular telephones due to the finite frequency bandwidth or spectrum available to the network. A voice call and/or electronic data can be delivered to a cellular telephone using a radio frequency (RF) signal at a certain operating frequency. Capacity in cellular networks may be increased by implementing a frequency reuse scheme. In such a scheme, RF signals with the same operating frequency may be used by different cellular telephone users in different cells. Typically, the different users are several cells apart to limit the interference between the RF signals of the different users. However, significant interference between the users may still exist which can decrease quality of the voice calls or corrupt the electronic data received by the different users.

An approach to reducing interference due to frequency reuse may include tilting antenna beams of base stations of cellular networks such that the transmitted RF signal is confined to the cell. Beam tilting may be performed in several different ways including mechanical, electrical, and optical methods. Electronic beam tilting can be used in cellular applications as well as satellite communication networks, smart weapons, radar applications, and other RF systems where RF signals may interfere with each other.

Decreases in a quality of service in such systems and applications can occur when two or more RF signals are in phase with each other resulting in the RF signals destructively interfering with each other. Beam tilting may be achieved by varying the phase of the transmitted RF signal. The phase variation can be performed in two ways, for example. First, the phase can be adjusted by changing the operating frequency of the signal. This may not be desirable in some applications, such as cellular applications, because the transmitted signal would not be properly decoded at the receiver. Secondly, electronic phase shifters can be used to vary the phase at a fixed operating frequency. However, traditional electronic phase shifters may be expensive as well as may have high power consumption requirements.

SUMMARY

Within embodiments described below, a device for phase shifting an RF signal for base station antenna is disclosed. The device includes a transmission line that delivers an RF signal from an RF transmitter to the base station antenna as well as a substrate with a top planar surface and a bottom planar surface. The device also includes a stationary ground plane coupled to the top planar surface of the substrate and a signal line on the bottom planar surface of the substrate. The signal line has an input port and an output port and is made of conducting material. The input port receives the RF signal with a certain phase from the RF transmitter then the conducting material transmits the RF signal across the bottom planar surface of the substrate to the output port. The RF signal has a different phase at than at the output port. The device further includes one or more types of defected ground structures on the top planar surface of the substrate. The defected ground structure may be a short stem dumbbell structure or a long stem dumbbell structure. The defected ground structures may shift the phase of the RF signal from the phase at the input port to the different phase at the output port. The difference between the phase at the input port and the phase at the output port is a phase shift of the RF signal. In addition, the device includes a movable ground plane that may cover a portion of the defected ground structures, the top planar surface of the substrate, and the stationary ground plane to further adjust the phase shift of the RF signal.

Another embodiment of the present disclosure includes a method for phase shifting an RF signal for a base station antenna that comprises receiving an RF signal with a certain phase at an input port of a signal line and transmitting the RF signal across the signal line to an output port. The signal line is on a bottom planar surface of a substrate. The method also includes shifting a phase of the RF signal from a phase at the input port to a different phase at the output port using one or more types of defected ground structures. The top of a stationary ground plane attached to a top planar surface of the substrate may be etched with the defected ground structures. Types of defected ground structures may include a short stem dumbbell structure and a long stem dumbbell structure. Further, a difference between the phase of the RF signal at the input port and the different phase at the output port is a phase shift of the RF signal. Additionally, the method includes further adjusting the phase shift of the RF signal by covering a portion of the one or more defected ground structures, the stationary ground plane, and the top planar surface of the substrate with a moveable ground plane and providing the RF signal with the different phase at the output port.

In yet another embodiment, another a method for phase shifting an RF signal for a base station antenna is disclosed using a transmission line that includes transmission line components such as signal line, a substrate, a stationary ground plane, defected ground structures, and a moveable ground plane. The method includes receiving a target beam tilt value at the user interface of the computer. The method also includes calculating a target phase shift based on the target beam tilt value and the dimensions of the transmission line and the transmission line components. Further, the method includes determining a target distance to slide the moveable ground plane to cover portions of the transmission line and the transmission line components to achieve the target phase shift. Additionally, the method includes sending instructions to a microcontroller to rotate a stepper motor a certain amount that translates to the target distance for sliding the moveable ground plane.

The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an example cellular network illustrating signal interference using a frequency reuse scheme;

FIG. 2 is an example functional block diagram of a cellular base station using a microstrip transmission line to phase shift an RF signal;

FIG. 3 is an example of a microstrip transmission line used to phase shift an RF signal;

FIG. 4 is another example of a microstrip transmission line used to phase shift an RF signal;

FIG. 5 is an example circuit model of example defected ground structures in a microstrip transmission line that phase shifts an RF signal;

FIG. 6 is an example functional block diagram of a phase shift system using a microstrip transmission line and stepper motor to control phase shift in an RF signal;

FIG. 7 is a block diagram illustrating an example computing device **700** used to control a stepper motor as part of an example phase shift system.

FIG. 8 is a flowchart for an example method for phase shifting an RF signal;

FIG. 9 is a flowchart for an example method for controlling a moveable ground plane of a microstrip transmission line to adjust a phase of an RF signal.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented herein. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the Figures, can be arranged, substituted, combined, separated, and designed in a wide variety of different configurations, all of which are explicitly contemplated herein.

A cellular network may have limited bandwidth or frequency spectrum available to transmit voice calls or electronic data (e.g. text messaging, multimedia messaging, web browsing, email, etc.) to network users with cellular telephones, smartphones, laptops, personal digital assistants (PDAs) or other user terminals. A cellular service provider may utilize different transmission schemes to maximize capacity to in the cellular network. Example transmission schemes may include Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA). Further, a transmission scheme utilizes a RF signal at a particular operating frequency in the frequency spectrum to deliver a voice call or electronic data to a particular user terminal. Further, to maximize capacity in the cellular network, the service provider may implement a frequency reuse scheme. A frequency reuse scheme allows different user terminals, separated by several cells, to use the same frequency to receive voice calls and electronic data. However, the RF signal to each different user terminal may interfere with each other to reduce the quality of voice calls or corrupt the electronic data.

FIG. 1 is an example cellular network **100** illustrating signal interference using a frequency reuse scheme. The cellular network **100** includes four cells, Cell **1** (**105**), Cell **2** (**110**), Cell **3** (**115**), and Cell **4** (**120**). In Cell **1** (**105**), a base station **125** transmits a RF signal A (**132**) to a User **1** Terminal (**134**). The RF signal A (**132**) may carry a voice call or electronic data and may be of the form A=M_1 sin({acute over (ω)}$_x$t+ψ_1) where M_1 is the amplitude, {acute over (ω)}$_x$ is the frequency, and ψ_1 is the phase of RF signal A. Alternatively, in Cell **4** (**120**) a base station **130** transmits a RF signal B (**140**) to a User Terminal **2** (**145**). The RF signal B (**14**) may also carry a voice call or electronic data to the User **2** Terminal (**145**) and may be of the form B=M_2 sin({acute over (ω)}$_x$t+ψ_2) where M_2 is the amplitude, {acute over (ω)}$_x$ is the frequency, and ψ_2 is the phase of RF signal B.

The cellular service provider may implement a frequency reuse scheme such that RF signals A and B have the same operating frequency {acute over (ω)}$_x$ ω_x. Consequently, User Terminal **2** (**145**) may receive RF signal A (**135**) from Cell **1** (**105**) such that RF signal A (**135**) may interfere with RF signal B (**140**) to distort the voice call or corrupt electronic data destined for User Terminal **2** (**145**). For example, if θ_1 is out of phase from θ_2, then RF signal A (**135**) and RF signal B (**140**) destructively interfere with each other resulting in a decrease in quality of service to User Terminal **2** (**145**).

Interference between RF signals in cellular networks may occur when two or more RF signals are out of phase with each other resulting in the RF signals destructively interfering with each other. A cellular service provider may implement several mechanisms to control a phase of an RF signal that may include using a microstrip transmission line. FIG. 2 is an example functional block diagram of a base station **200** for Cell **1** and a base station **217** for Cell **4**, each base station using a microstrip transmission line to control a phase shift of the RF signal. The base station **200** for Cell **1** may have an RF transmitter **205** that generates an RF signal A=M_1 sin({acute over (ω)}$_x$t) where M_1 is the amplitude and {acute over (ω)}$_x$ is the frequency. The RF signal may then be transmitted over a microstrip transmission line **210**. The microstrip transmission line **210** may shift or control a phase of the RF signal A. The microstrip transmission line **210** may provide an output RF signal A with a phase shift such as A=M_1 sin({acute over (ω)}$_x$t+θ_1) to a base station antenna **215** where θ_1 is the phase shift. Further, the base station **217** for Cell **4** may also have an RF transmitter **220** that generates an RF signal B=M_2 sin({acute over (ω)}$_x$t) where M_2 is the amplitude and {acute over (ω)}$_x$ is the frequency. The RF signal B may then be transmitted over a microstrip transmission line **225** to shift or control a phase of RF signal B. The microstrip transmission **225** line may provide an output RF signal B with a phase shift such as B=M_2 sin({acute over (ω)}$_x$t+θ_2) where θ_2 is the phase shift. However, the service provider may construct the microstrip transmission lines (**210**, **225**) to control θ_1 and θ_2 such that the two RF signals do not interfere with each other when transmitted to different user terminals in a cellular network.

In example embodiments, electronic phase shifters may be incorporated in a microstrip transmission line that is coupled between an RF transmitter at a cellular base station in the base station antenna or antenna array. The microstrip transmission line may include a substrate with a stationary ground plane attached to one side and the signal line carrying the RF signal from the RF transmitter on an opposite side. Defected Ground Structures (DGS) may be etched into the stationary ground plane. DGS structures may change the capacitance and inductance of the microstrip transmission line and thus vary the phase of the RF signal. Further, the transmission line may include a moveable ground plane that covers portions of the DGS structures, altering the capacitance and inductance to further adjust the phase of the RF signal. An equivalent inductance-capacitance (LC) circuit may be used to model the effects of the DGS structures (may be fully or partially covered by moveable ground plane) on the RF signal carried by the transmission line. DGS structures may take many different forms or shapes. These may include triangular, elliptical, rectangular, and dumbbell forms. A different LC circuit may be used to model each different form or shape of a DGS structure. Values for the inductance and capacitance of the LC circuit model may be a function of the dimensions of the DGS structures. Therefore, the phase of the RF signal traveling along the transmission line can be shifted by varying the dimensions of the DGS structures.

In addition, a base station antenna system may have multiple antenna elements in an array and a separate phase shifter may be connected at the input of each antenna element. For example, an array of five antenna elements may require five different phase shifters. The phase shifters can be separate units or as a single phase shifter bank with five parallel signal lines and the corresponding DGS structures etched or printed on the bottom of the transmission line. In such an example, the movable ground plane may be a single unit that slides over the entire phase shifter bank.

FIG. 3 is an example of a microstrip transmission line **300** used to phase shift an RF signal. The microstrip transmission line **300** may have an input port and an output port. The input port may be coupled to an RF transmitter that generates and modulates the RF signal. Further, the input port transmits the RF signal across the microstrip transmission line along a signal line **320** to the output port. In addition, the output port may be coupled to a base station antenna that may direct the RF signal to a user terminal. The microstrip transmission line **300** may also include a substrate **310**. The substrate **310** may comprise several different types of materials that may include a type of dielectric material, for example. On one side of the substrate **310** is the signal line **320**. The signal line **320** comprises conducting material that carries the RF signal from the input port to the output port. Coupled onto the opposite side of the substrate **310** is a stationary ground plane **330**. It will be shown when describing FIG. 4 that Defected Ground Structures (DGS) may be etched into the stationary ground plane **330** to shift a phase of the RF signal as the RF signal travels across the microstrip transmission line **300** along the signal line **320**. In addition, a moveable ground plane **340** may be used to cover a portion or all of the stationary ground plane **330** including a portion or all of the DGS structures to further adjust the phase of the RF signal, for example.

FIG. 4 illustrates a microstrip transmission line **400** used to phase shift an RF signal. A stationary ground plane **430** is coupled to a substrate (not shown). A signal line **420** is coupled to an opposite side of the substrate with respect to the stationary ground plane **430**. A series of Defected Ground Structures (DGS) **490** may be etched into the stationary ground plane **430** comprising one or more unit DGS structures (**410**). A DGS structure is generated by etching conducting material into certain patterns on the stationary ground plane **430**. The series of DGS structures may comprise a nested dumbbell pattern **410**, for example. That is, the unit DGS structure **410** may include two short stem dumbbells **430** nested within a long stem dumbbell pattern **420**. The series of DGS structures **490** may shift a phase of an RF signal traveling along the signal line **420** based on the transmission line components (e.g. substrate, signal line **420**, stationary ground plane **430**, and a moveable ground plane **440**). In addition, the moveable ground plane **440** may be manually or motor controlled to cover a portion of the stationary ground plane **430** including a portion of the series of DGS structures **490** to further adjust the phase of the RF signal.

Dimensions of the ground plane as well the as dimensions of the DGS structures may effect the phase shift of the RF signal traveling along the signal line. The dimensions that vary a phase of the RF signal may include the length (L) and width (W) of the stationary ground plane **430**. Further dimensions that effect the phase may include length L_1 and width W_1 of a unit **410** in the series of DGS structures. In addition, the width W_S of the signal line **420** may vary the phase. Example dimensions may include L=113 mm, W=70 mm, L_1=8 mm, W_1=40 mm, and W_S=3 mm.

FIG. 5 is an example circuit model **550** of an example defected ground structures **500** in a microstrip transmission line that phase shifts an RF signal. As discussed in FIG. 4, the dimensions of transmission components as well as DGS structures may contribute to the phase shift of the RF signal. The DGS structure may be a nested dumbbell structure **500** such that two short stem dumbbell DGS structures **530** are nested within a long stem dumbbell DGS structure **532**. The short stem dumbbell DGS structure **530** comprises two rectangular or square defects (**505** and **512**) connected by a narrow slot **510**. A length of the rectangular defects (**505** and **512**) is “a” and a width of the rectangular defects (**505** and **512**) is “b”. The width of the narrow slot **510** is g_S. Alternatively, the long stem dumbbell DGS structure **532** comprises two narrow rectangular defects (**515** and **525**) with length “y” and width “z” connected by a narrow slot **520** with width g_L.

DGS structures can shift the phase of the signal because the DGS structures change inductance and capacitance of the transmission line based on DGS structure dimensions. An etched defect in the ground plane may disturb current distribution in a stationary ground plane. Such disturbances can change characteristics of a transmission line such as line capacitance and inductance. Etched areas of a DGS structure may give rise to increasing the effective capacitance and inductance of a transmission line. Thus, an example equivalent LC circuit **550** can represent a DGS structure **500**, as shown in FIG. 5. Values for the effective capacitance and effective inductance in the equivalent parallel LC circuit model may be based on the dimensions of the DGS structures.

The dumbbell structure includes a narrow stem cell connected to two wide etched (e.g. rectangular) regions which contribute to a net effective capacitance and inductance of the transmission line, respectively. The stem width g_S **510** and g_L **520** are inversely proportional to the amount of effective capacitance. That is, a decrease in width of either stem g_S **510** and g_L **520** increases the effective capacitance of the transmission line. The wide etched rectangular areas of dimension “a” **505** and “b” **512** and “y” **515** and “z” **525**, respectively, are directly proportional to the effective inductance of the transmission line. That is, an increase in the area of rectangular regions (**505**, **515**, **530**) increases the inductance of the transmission line.

The parallel LC circuit model in FIG. 5 may show that the DGS structures behave like a low pass or bandgap filter. Accordingly, a resonance occurs at a certain frequency due to the parallel LC circuit. The resonance frequency is a frequency at which a parallel LC circuit has infinite impedance. The rectangular defects of the short stem dumbbell DGS structure **530** increase route length of a current and the effective inductance of the transmission line. The narrow slot of the short stem dumbbell DGS structure **510** may accumulate charge and increases the effective capacitance of the transmission line. Alternatively, when the etched gap distance decreases, the effective capacitance decreases such that the attenuation pole location (resonance frequency) moves up to a higher frequency. Further, as the etched area of the unit DGS structure increases, the effective inductance increases giving rise to a lower cutoff frequency or the 3 dB point of the low pass or bandgap filter, for example.

Further, analyzing the parallel LC circuit model in FIG. 5 shows an example in which the DGS structure shifts the phase of an RF signal traveling along a signal line of a transmission line. The inductance and capacitance in the parallel LC circuit gives rise to reactance in the circuit. Alternatively, the circuit may contain impedances that have resistive components as well as the reactive components. When an RF signal is applied to the input port of a parallel LC circuit having both resistive and reactive components, the RF signal may be shifted in phase at the output port of the circuit. The phase of the signal at the output port could be given by

$\theta=\beta 1$ (1)

where β is the propagation constant and 1 is the physical length of the transmission line. Further

$\beta=\omega(LC)^{1/2}$ (2)

where ω is the frequency of operation, L and C are the equivalent inductance and capacitance, of the transmission line respectively. Thus from the above equations (1) and (2), the change in the line inductance and capacitance attributed by the DGS structures can, in turn, change the phase of the output RF signal.

Analyzing the parallel LC circuit in FIG. 5, an overall impedance (Z) can be determined based on the values of R, L, and C. The overall impedance of the LC circuit may be of the form Z=R+jX where R represents the resistive and X represents the reactive components of the overall impedance Z, respectively. Hence, when an RF signal is applied to an input port of the parallel LC circuit, then the RF signal at an output port may have a shifted phase. The shifted phase may be equal to the arctan(X/R).

In one example, the DGS structures and covering of the structures by a moveable ground plane may give rise to inductance and capacitance values to the transmission line of about 3.6 nH and about 0.1 pF, respectively, for example. Further, the resistive component of the overall impedance of the transmission line may be equal to about 50Ω. The overall impedance of the parallel LC circuit model for the transmission line for an RF signal operating at a frequency of about 8 GHz may be found by the following:

Z = R + j X = R - j ω L ω 2 LC - 1 (3)

Thus, for the values for R, L, C and {acute over (ω)} (2πf where f=8 GHz), the overall impedance is given by Z=50−22.5 j. Further, the phase shift of the RF signal is given by the arctan(−22.5/50)=24 degrees. Therefore, the RF signal at the output port of the transmission line has a phase shift equal to about 24 degrees.

In addition, the phase shift of the RF signal may be adjusted by varying the reactive components (inductance or capacitance) of the parallel LC circuit. Hence, the phase of an RF signal may be varied using a transmission line by varying the dimensions of the DGS structures which give rise to the values of the reactive components (inductance and capacitance) components of the transmission line. Values for the inductance and capacitance vary depending on the shape and dimensions of the DGS structures. The equivalent circuit of a DGS structure is derived by simulating a single DGS structure along with a microstrip line using simulation and test equipment such as a 3D EM simulator. For example, for a nested dumbbell structure, simulation results may show a one pole low pass filter response with a 3 dB cut off frequency and an attenuation pole frequency. Values of equivalent L and C can be calculated by the following formulae:

$C=\omega_0/Z_0 g_1(\omega_0{}^2-\omega_c{}^2)$ (4)

$L=¼\pi^2 f_0{}^2 C$ (5)

where ω_0 is the angular frequency at the location of the attenuation point, ω_c is the angular frequency at the 3 dB cutoff point, Z_0 is the characteristic impedance of the transmission line, g_1 is a prototype value of a Butterworth low pass filter of first order=2, f_0 is the frequency at the 3 db cutoff point.

In addition, a moveable ground plane covering the etched DGS structures on the stationary ground plane may also vary the inductance and capacitance of the transmission line resulting in adjusting the phase of the RF signal traveling along the signal line. The movable ground plane that slides above the DGS structures can be made to fully open or fully close or partially close the DGS structures. When the DGS structures are fully closed there is no reactive loading in the line and the signal line directly transmits the signal in the input port to the output port with a phase proportional to the physical length of the line, also called the reference phase.

When the movable ground plane is kept at fully open position, the maximum reactive loading occurs and thus, the signal at the output port has a shifted phase when compared to the reference phase. The effective phase shift between the fully closed and fully open state is given by

Effective maximum phase shift=Phase at fully open state−Reference phase (6)

However, when the movable ground plane is at intermediate positions resulting in partially opened defected ground structures, the transmission line may have reactive loading less than the maximum loading due to the fully open stage. Thus, intermediate phase values which are less than that obtained in the fully open stage and greater than that obtained in the fully closed stage are achieved. For example if a line of length X has a reference output phase of 20 degrees in fully closed stage and 200 degrees in fully open stage, then the movement of the movable ground plane would result in phase values in between 20 and 200 degrees.

The phase shift of the RF signal can range from about 0 degrees when the moveable ground plane is fully open (covers no portion of the stationary ground plane and/or any portion of the DGS structures) up to about 190 degrees when fully closed (covers almost every portion of the stationary ground plane and/or almost every portion of the DGS structures), for example.

FIG. 6 is an example functional block diagram of a phase shift system **600** using a microstrip transmission line **610** and stepper motor **620** to control phase shift in an RF signal. The microstrip transmission line **610** receives a signal from an RF transmitter **605**, and subsequently passes a phase shift signal to an antenna **615**.

A moveable ground plane (not shown) of a microstrip transmission line may further adjust the phase shift of an RF signal by covering a portion of a stationary ground plane and portions of a series of DGS structures. The moveable ground plane may be controlled manually or by the stepper motor **620**. A stepper motor (or step motor) may be a brushless, synchronous electric motor that can divide a full rotation of a motor into a large number of steps. A position of the stepper motor **620** can be controlled precisely, without any feedback mechanism, for example.

A stepper motor may have multiple toothed electromagnets arranged around a central gear-shaped piece. The electromagnets are energized by an external control circuit, such as a microcontroller. To make the motor shaft turn, first one electromagnet is given power, which makes the gear's teeth magnetically attracted to the electromagnet's teeth. When the gear's teeth are thus aligned to the first electromagnet, the teeth are slightly offset from the next electromagnet. Hence, when the next electromagnet is turned on and the first is turned off, the gear rotates slightly to align with the next electromagnet, and from there the process is repeated. Each slight rotation may be called a “step,” with an integer number of steps making a full rotation. In that way, the motor can be turned by a precise angle.

The stepper motor **620** may be controlled by a motor microcontroller **630** such that the phase of the RF signal can be controlled in a precise manner to reduce interference with other RF signals on the same frequency destined to other user terminals. The motor microcontroller **630** may be programmed in advance or in real-time by computer **625** to adjust the phase of an RF signal based on the dimensions of the transmission line, substrate, signal line, stationary and moveable ground planes as well as the DGS structures and other transmission line components.

The computer **625** may include one or more user interfaces and/or electronic input/output ports to receive the dimensions of the transmission line components as well as a target beam tilt value and a target phase shift for the RF signal. The method in which the phase is adjusted based on the target beam tilt value and the dimensions and the target phase shift is discussed when describing FIG. 9.

FIG. 7 is a block diagram illustrating an example computing device **700** that is used to control a stepper motor as part of an example phase shift system. In a very basic configuration **701**, computing device **700** typically includes one or more processors **710** and system memory **720**. A memory bus **730** can be used for communicating between the processor **710** and the system memory **720**. Depending on the desired configuration, processor **710** can be of any type including but not limited to a microprocessor (μP), a microcontroller (μC), a digital signal processor (DSP), or any combination thereof. Processor **710** can include one more levels of caching, such as a level one cache **711** and a level two cache **712**, a processor core **713**, and registers **714**. The processor core **713** can include an arithmetic logic unit (ALU), a floating point unit (FPU), a digital signal processing core (DSP Core), or any combination thereof. A memory controller **715** can also be used with the processor **710**, or in some implementations the memory controller **715** can be an internal part of the processor **710**.

Depending on the desired configuration, the system memory **720** can be of any type including but not limited to volatile memory (such as RAM), non-volatile memory (such as ROM, flash memory, etc.) or any combination thereof. System memory **720** typically includes an operating system **721**, one or more applications **722**, and program data **724**. Application **722** includes control input processing algorithm **723** that is arranged to provide inputs to the electronic circuits, in accordance with the present disclosure. Program Data **724** includes control input data **725** that is useful for minimizing power consumption of the circuits, as will be further described below. In some example embodiments, application **722** can be arranged to operate with program data **724** on an operating system **721** such that power consumption by an electronic circuit is minimized. This described basic configuration is illustrated in FIG. 7 by those components within dashed line **701**.

Computing device **700** can have additional features or functionality, and additional interfaces to facilitate communications between the basic configuration **701** and any required devices and interfaces. For example, a bus/interface controller **740** can be used to facilitate communications between the basic configuration **701** and one or more data storage devices **750** via a storage interface bus **741**. The data storage devices **750** can be removable storage devices **751**, non-removable storage devices **752**, or a combination thereof. Examples of removable storage and non-removable storage devices include magnetic disk devices such as flexible disk drives and hard-disk drives (HDD), optical disk drives such as compact disk (CD) drives or digital versatile disk (DVD) drives, solid state drives (SSD), and tape drives to name a few.

Exemplary computer storage media can include volatile and nonvolatile, removable and non-removable media implemented in any method or technology for storage of information, such as computer readable instructions, data structures, program modules, or other data.

System memory **720**, removable storage **751** and non-removable storage **752** are all examples of computer storage media. Computer storage media includes, but is not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by computing device **700**. Any such computer storage media can be part of device **700**.

Computing device **700** can also include an interface bus **742** for facilitating communication from various interface devices (e.g., output interfaces, peripheral interfaces, and communication interfaces) to the basic configuration **701** via the bus/interface controller **740**. Exemplary output interfaces **760** include a graphics processing unit **761** and an audio processing unit **762**, which can be configured to communicate to various external devices such as a display or speakers via one or more A/V ports **763**. Exemplary peripheral interfaces **770** include a serial interface controller **771** or a parallel interface controller **772**, which can be configured to communicate with external devices such as input devices (e.g., keyboard, mouse, pen, voice input device, touch input device, etc.) or other peripheral devices (e.g., printer, scanner, etc.) via one or more I/O ports **773**. An exemplary communication interface **780** includes a network controller **781**, which can be arranged to facilitate communications with one or more other computing devices **790** over a network communication via one or more communication ports **782**. The Communication connection is one example of a communication media. Communication media may typically be embodied by computer readable instructions, data structures, program modules, or other data in a modulated data signal, such as a carrier wave or other transport mechanism, and includes any information delivery media. A “modulated data signal” can be a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media can include wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, radio frequency (RF), infrared (IR) and other wireless media. The term computer readable media as used herein can include both storage media and communication media.

Computing device **700** can be implemented as a portion of a small-form factor portable (or mobile) electronic device such as a cell phone, a personal data assistant (PDA), a personal media player device, a wireless web-watch device, a personal headset device, an application specific device, or a hybrid device that include any of the above functions. Computing device **700** can also be implemented as a personal computer including both laptop computer and non-laptop computer configurations.

FIG. 8 is a flowchart for an example method for phase shifting an RF signal. The method may comprise receiving an RF signal at an input port of a signal line of a microstrip transmission line, as shown at block **810**, from an RF transmitter or some other device within a base station. A further step may be transmitting the RF signal across the signal line to an output port, as shown at block **820**. The signal line may comprise of conducting material that is coupled to one side of a substrate of the transmission line. Additionally, one or more types of DGS structures may be used to phase shift the RF signal, as shown at block **830**. The DGS structures may be constructed by etching conducting material onto a stationary ground plane of the transmission line. Further, the stationary ground plane is coupled onto an opposite side of the substrate with respect to the signal line. Also, the phase shift of the RF signal may be adjusted by covering a portion of the one or more defected ground structures, the stationary ground plane, and the associated planar surface of the substrate with a moveable ground plane, as shown at block **840**. The method may include controlling the moveable ground plane to cover the DGS structures, stationary ground plane, and the substrate using a stepper motor and/or computer, as shown at block **850**. Another step in the method may be providing the phase shifted RF signal at an output port such that the RF signal can be transmitted to a base station antenna, as shown at block **860**.

FIG. 9 is a flowchart **900** for an example method for controlling a moveable ground plane of a microstrip transmission line to adjust a phase of an RF signal. As discussed when describing FIG. 6, a stepper motor may control a moveable ground plane to cover portions of a microstrip transmission line as part of a phase shift system to further adjust the phase of an RF signal. A microcontroller and a computer together may control the stepper motor based on the dimensions of transmission line components. The example method may include the computer receiving a target beam tilt value of the antenna at a user interface and/or input/output port, as shown at block **930**. The beam tilt of an antenna in an antenna array may correspond to a phase shift in a transmitted RF signal. The method may calculate a target phase shift be provided to the input of each antenna element in the base station antenna array using an automatic computer based program, as shown at block **935**. Thereafter, the computer may determine a target distance to slide the moveable ground plane and cover portions of the transmission line components to achieve the target phase shift, as shown at block **940**, based on the inductance, capacitance, and resistive effects arising from etched DGS structures on the stationary ground plane and covering provided by the moveable ground plane. The target distance may be obtained from a look-up table as shown in Table 1 linked to a computer program. The look-up table may be generated by phase measurements of an RF signal at an output port of a transmission line using a network analyzer while varying the movable ground plane

Another step in the method includes sending instructions to a microcontroller that controls the stepper motor, as shown at block **950**. An additional step may include the microcontroller adjusting the stepper motor which in turn slides the moveable ground plane, as shown at block **960**, to the target distance thereby adjusting the phase of the RF signal to the target phase shift. Additional steps in the method may include the computer receiving as input the dimensions of the transmission line components, at a user interface and/or input/output port. The dimensions may include the microstrip transmission line itself, a substrate, a signal line, a stationary and a moveable ground planes as well DGS structures etched into the stationary ground plane. Thereafter the computer may then model the transmission line components as an equivalent parallel LC circuit and calculate inductance, capacitance, and resistive values of the LC circuit.

Example values of distances to slide the moveable ground plane to cover a microstrip transmission line with a series DGS structures and associated phase shifts are shown in Table 1. The unit DGS structure of the series DGS structures comprises of two short stem dumbbell structures nested in a long stem dumbbell structure.

TABLE 1

Sliding Length (mm)	Phase Shift (Deg)
Fully Open	0
2	39
4	54
6	70
8	78
10	86
12	99
14	108
16	127
18	150
20	178
22	182
24	183
26	186
28	188
30	188
32	188
34	189
36	189
38	189
Fully Closed	190

In general, it should be understood that the circuits described herein may be implemented in hardware using integrated circuit development technologies, or yet via some other methods, or the combination of hardware and software objects that could be ordered, parameterized, and connected in a software environment to implement different functions described herein. For example, the present application may be implemented using a general purpose or dedicated processor running a software application through volatile or non-volatile memory. Also, the hardware objects could communicate using electrical signals, with states of the signals representing different data.

It should be further understood that this and other arrangements described herein are for purposes of example only. As such, those skilled in the art will appreciate that other arrangements and other elements (e.g. machines, interfaces, functions, orders, and groupings of functions, etc.) can be used instead, and some elements may be omitted altogether according to the desired results. Further, many of the elements that are described are functional entities that may be implemented as discrete or distributed components or in conjunction with other components, in any suitable combination and location.

It should be further understood that this and other arrangements described herein are for purposes of example only. As such, those skilled in the art will appreciate that other arrangements and other elements (e.g. machines, interfaces, functions, orders, and groupings of functions, etc.) can be used instead, and some elements may be omitted altogether according to the desired results. Further, many of the elements that are described are functional entities that may be implemented as discrete or distributed components or in conjunction with other components, in any suitable combination and location.

The present disclosure is not to be limited in terms of the particular embodiments described in this application, which are intended as illustrations of various aspects. Many modifications and variations can be made without departing from its spirit and scope, as will be apparent to those skilled in the art. Functionally equivalent methods and apparatuses within the scope of the disclosure, in addition to those enumerated herein, will be apparent to those skilled in the art from the foregoing descriptions. Such modifications and variations are intended to fall within the scope of the appended claims. The present disclosure is to be limited only by the terms of the appended claims, along with the full scope of equivalents to which such claims are entitled. It is to be understood that this disclosure is not limited to particular methods, reagents, compounds compositions, or biological systems, which can, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity.

It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as “open” terms (e.g., the term “including” should be interpreted as “including but not limited to,” the term “having” should be interpreted as “having at least,” the term “includes” should be interpreted as “includes but is not limited to,” etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases “at least one” and “one or more” to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles “a” or “an” limits any particular claim containing such introduced claim recitation to embodiments containing only one such recitation, even when the same claim includes the introductory phrases “one or more” or “at least one” and indefinite articles such as “a” or “an” (e.g., “a” and/or “an” should be interpreted to mean “at least one” or “one or more”); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should be interpreted to mean at least the recited number (e.g., the bare recitation of “two recitations,” without other modifiers, means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to “at least one of A, B, and C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “a system having at least one of A, B, and C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to “at least one of A, B, or C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “a system having at least one of A, B, or C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms. For example, the phrase “A or B” will be understood to include the possibilities of “A” or “B” or “A and B.”

In addition, where features or aspects of the disclosure are described in terms of Markush groups, those skilled in the art will recognize that the disclosure is also thereby described in terms of any individual member or subgroup of members of the Markush group.

As will be understood by one skilled in the art, for any and all purposes, such as in terms of providing a written description, all ranges disclosed herein also encompass any and all possible subranges and combinations of subranges thereof. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, tenths, etc. As a non-limiting example, each range discussed herein can be readily broken down into a lower third, middle third and upper third, etc. As will also be understood by one skilled in the art all language such as “up to,” “at least,” “greater than,” “less than,” and the like include the number recited and refer to ranges which can be subsequently broken down into subranges as discussed above. Finally, as will be understood by one skilled in the art, a range includes each individual member. Thus, for example, a group having 1-3 cells refers to groups having 1, 2, or 3 cells. Similarly, a group having 1-5 cells refers to groups having 1, 2, 3, 4, or 5 cells, and so forth.

While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

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US20090231068A1 *	2008-03-12	2009-09-17	Amitabh Das	Filter-Attenuator Chip Device
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Publication number	Priority date	Publication date	Assignee	Title
CN104732887A *	2015-04-03	2015-06-24	京信通信技术(广州)有限公司	Antenna downward inclination angle display device and antenna
Family To Family Citations				
US9306257B2 *	2014-04-02	2016-04-05	Litepoint Corporation	RF phase shift apparatus having an electrically coupled path separated from an electromagnetically coupled path to provide a substantially constant phase difference therebetween
US20160308661A1 *	2015-04-15	2016-10-20	Rohde & Schwarz Gmbh & Co. Kg	Communication device and method for wireless signal transmission

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* Cited by examiner, † Cited by third party, ‡ Family to family citation

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US20070188390A1	2007-08-16	Antenna system having receiver antenna diversity and configurable transmission antenna and method of management thereof
Tam et al.	1999	Compact circular sector and annular sector dielectric resonator antennas
Hum et al.	2010	Analysis and design of a differentially-fed frequency agile microstrip patch antenna

Priority And Related Applications

Parent Applications (1)

Application	Priority date	Filing date	Relation	Title
US12723161	2010-01-28	2010-03-12	Continuation	Devices and Methods for Phase Shifting a Radio Frequency (RF) Signal for a Base Station Antenna

Priority Applications (4)

Application	Priority date	Filing date	Title
IN222CH2010		2010-01-28	
IN222/CHE/2010		2010-01-28	
US12723161	2010-01-28	2010-03-12	Devices and Methods for Phase Shifting a Radio Frequency (RF) Signal for a Base Station Antenna
US13710346	2010-01-28	2012-12-10	Devices and methods for phase shifting a radio frequency (RF) signal for a base station antenna

Applications Claiming Priority (1)

Application	Filing date	Title
US13710346	2012-12-10	Devices and methods for phase shifting a radio frequency (RF) signal for a base station antenna

Legal Events

Date	Code	Title	Description
2015-06-09	CC	Certificate of correction	

2018-03-13	MAFP	**Free format text**: PAYMENT OF MAINTENANCE FEE, 4TH YEAR, LARGE ENTITY (ORIGINAL EVENT CODE: M1551) **Year of fee payment**: 4

6729

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28 JUL 2014

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Renewal Certificate
(Rule 80(4) of Patent Rules)

RC Number : 9026 I 2802

RC issue date: 09/Jul/2014

Patent Number: 198254
Application Number: 488/MAS/2002
Date of Application: 27/Jun/2002
Grantee : THIAGARAJAR COLLEGE OF ENGINEERING
Patentee (current assignee) : THIAGARAJAR COLLEGE OF ENGINEERING

Certified that the patent number mentioned above has been renewed upon receipt of ₹26400 vide CBR No. 11233 dated 20/Jun/2014 and continued for:

Year:	Amount:	Valid Upto:	Year:	Amount:	Valid Upto:
3rd year			12th year		
4th year			13th year	26400	27/Jun/2015
5th year			14th year		
6th year			15th year		
7th year			16th year		
8th year			17th year		
9th year			18th year		
10th year			19th year		
11th year			20th year		

Extension fee for Nil month(s) : ₹0
Additional fee for restoration : ₹0
Total fee : ₹26400
Due date for next renewal is : 27/Jun/2015
Address for service : M/S. THIAGARAJAR COLLEGE OF ENGINEERING, TIRUPPARANKUNRAM, MADURAI 625 015
Additional address for service :

(For Controller of Patents)

Texture Identification

Abstract

Technologies are generally described for determining a texture of an object. In some examples, a method for determining a texture of an object includes receiving a two-dimensional image representative of a surface of the object, estimating a three-dimensional (3D) projection of the image, transforming the 3D projection into a frequency domain, projecting the 3D projection in the frequency domain onto a spherical co-ordinate system, and determining the texture of the surface by analyzing spectral signatures extracted from the 3D projection on the spherical co-ordinate system.

US20120106830A1
US Application

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Current Assignee : THIAGARAJAR COLLEGE OF ENGR

Original Assignee: THIAGARAJAR COLLEGE OF ENGR

Priority date : 2010-11-02

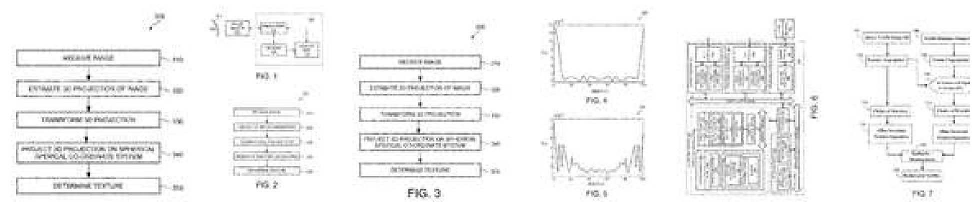
Family: US (2)

Date	App/Pub Number	Status
2010-11-02	US12938193	Active
2012-05-03	US20120106830A1	Application
2014-04-15	US8699785B2	Grant
2014	US14228606	Active

Info: Patent citations (5), Non-patent citations (1), Cited by (6), Legal events, Similar documents, Priority and Related Applications

External links: USPTO, USPTO Assignment, Espacenet, Global Dossier, Discuss

Images (10)



Classifications

G06T7/42 Analysis of texture based on statistical description of texture using transform domain methods

View 5 more classifications

Claims (20)

1. **1**. A method for determining a texture of an object, the method comprising:

   receiving a two-dimensional image representative of a surface of the object;

estimating a three-dimensional (3D) projection of the image;

transforming the 3D projection into a frequency domain;

projecting the 3D projection in the frequency domain onto a spherical co-ordinate system; and

determining the texture of the surface by analyzing spectral signatures extracted from the 3D projection on the spherical co-ordinate system.

2. **2**. The method of claim 1, wherein the transforming the 3D projection comprises using a 3D Fourier transform.

3. **3**. The method of claim 1, wherein the estimating the 3D projection comprises projecting the two dimensional image on to a Cartesian coordinate system.

4. **4**. The method of claim 1, wherein the determining the texture comprises generating spectral signatures for a tilt angle variation and an orientation angle variation.

5. **5**. The method of claim 4, further comprising:

calculating a tilt angle value based on a comparison of sum of peak to peak distance between the spectral signature for the tilt angle variation and a reference spectral signature for the tilt angle variation;

calculating an orientation angle value based on a comparison of sum of peak to peak distance between the spectral signature for the orientation angle variation and a reference orientation angle variation; and

generating a texture value based on the tilt angle value and the orientation angle value.

6. **6**. The method of claim 5, wherein the texture value is the sum of the tilt angle value and the orientation angle value.

7. **7**. The method of claim 5, further comprising selecting a comparison that generates a minimum texture value.

8. **8**. A system for determining a texture of an object, the system comprising:

a processor configured to:

access a two-dimensional (2D) representative of a surface of the object;

calculate a plurality of parameters for the image;

classify the surface into at least one texture type from a plurality of texture types; wherein the texture type is based on the plurality of parameters and each texture type comprises a plurality of reference texture values;

generate spectral signatures of the surface; and

determine the texture of the surface from the spectral signatures; and

a memory configured to store a plurality of reference texture images, each reference texture image having corresponding reference spectral signatures.

9. **9**. The system of claim 8, wherein the plurality of parameters is selected from the group consisting of homogeneity, directionality, regularity and roughness.

10. **10**. The system of claim 8, wherein the plurality of texture types is selected from the group consisting of homogenous texture, directional texture, regular texture and rough texture.

11. **11**. The system of claim 8, wherein the processor is configured to classify the surface into a single texture type.

12. **12**. The system of claim 8, wherein the processor is configured to generate spectral signatures using a transform function.

13. **13**. The system of claim 12, wherein the transform function is selected based on the texture type of the image.

14. **14**. The system of claim 8, wherein the spectral signatures comprise a spectral signature for a rotation parameter, a spectral signature for a scaling parameter and a spectral signature for translation parameter.

15. **15**. The system of claim 14, wherein the processor is configured to generate the spectral signature for the rotation parameter by:

estimating a three dimensional (3D) projection of the image;

transforming the 3D projection into a frequency domain;

projecting the 3D projection in the frequency domain on to a spherical co-ordinate system; and

generating the spectral signature from the 3D projection on the spherical co-ordinate system.

16. **16**. A computer program product, for use in a computing system including a processor and a memory, for implementing a method for performing texture identification of an object, the computer program product comprising one or more physical computer readable medium having stored thereon computer-executable instructions that, when executed by the processor, causes the computing system to:

access a two-dimensional image representative of a surface of the object;

estimate a three-dimensional (3D) projection of the image;

transform the 3D projection into a frequency domain;

project the 3D projection in the frequency domain on to a spherical co-ordinate system; and

determine the texture of the surface by analyzing spectral signatures extracted from the 3D projection on the spherical co-ordinate system.

17. **17**. The computer program product of claim 16, wherein the estimation of the 3D projection is by projecting the two dimensional image on to a Cartesian coordinate system.

18. **18**. The computer program product of claim 16, wherein the computer-executable instructions, when executed by the processor, further cause the computing system to generate spectral signatures for a tilt angle variation and an orientation angle variation.

19. **19**. The computer program product of claim 18, wherein the computer-executable instructions, when executed by the processor, further cause the computing system to:

calculate a tilt angle value based on a comparison of sum of peak to peak distance between the spectral signature for the tilt angle variation and a reference spectral signature for tilt angle variation;

calculate an orientation angle value based on a comparison of a sum of peak to peak distance between the spectral signature for the orientation angle variation and a reference orientation angle variation; and

generate a texture value based on the tilt angle value and the orientation angle value.

20. **20**. The computer program product of claim 19, wherein the computer-executable instructions, when executed by the processor, further cause the computing system to select a comparison that generates a minimum texture value.

Description

BACKGROUND

[0001] Applications currently exist that analyze an image of an object to extract information about its texture. The extracted texture information may then be used by other applications. For example, the texture information serves as a low level descriptor for content-based indexing and retrieving. Content based indexing and retrieving is often used in several industries such the textile industry, tile industry, crystal industry and the like.

[0002] Current content-based retrieval techniques begin by analyzing photographic images of the object. Typically, a first level of analysis is performed manually by an operator. Such operators visually examine the image to determine the texture of the object. However, the determination of the texture is not very accurate. In addition, the operator may not accurately perceive a texture image that has undergone geometrical transformation such as rotation or scaling.

[0003] Numerous techniques have been developed to consider the geometric transformation of the image while extracting the texture information. Rotation invariant feature extraction is one such technique that takes into consideration the rotation of the image while extracting the feature of the texture. However, most rotation invariant feature extraction techniques are based on image rotation and do not take into account physical surface rotation of the image.

[0004] Surface rotation invariant techniques have been developed to address the surface rotation parameters related to image rotation. However, most surface rotation invariant techniques require at least three images for processing thereby increasing processing complexity and associated costs. In addition, in most cases three images may not be available for processing.

SUMMARY

[0005] Briefly, according to one embodiment of the present disclosure, a method for determining a texture of an object is provided. The method includes receiving a two-dimensional image representative of a surface of the object and estimating a three-dimensional (3D) projection of the image. The 3D projection is transformed into a frequency domain and then projected on to a spherical co-ordinate system. The texture of the surface is determined by analyzing spectral signatures extracted from the 3D projection on the spherical co-ordinate system.

[0006] In another embodiment, a system for determining a texture of an object is provided. The system includes a processor configured to access a two-dimensional image representative of a surface of the object and estimate a three-dimensional (3D) projection of the image. The 3D projection is transformed into a frequency domain, and projected on to a spherical co-ordinate system. The processor is further configured to determine the texture of the surface by analyzing spectral signatures extracted from the 3D projection on the spherical co-ordinate system. The system further includes memory configured to store several reference texture images.

[0007] In another embodiment, a method for determining a texture of an object is provided. The method includes receiving a two-dimensional (2D) representative of a surface of the object, calculating several parameters for the image, and classifying the surface into at least one texture type from a set of texture types. The texture type is based on the calculated parameters and each texture type comprises corresponding reference spectral signatures. The method further comprises generating spectral signatures of the surface and determining the texture of the surface from the spectral signatures.

[0008] In another embodiment, a system for determining a texture of an object is provided. The system includes a processor configured to access a two-dimensional (2D) representative of a surface of the object, calculate a plurality of parameters for the image, and classify the surface into at least one texture type from a plurality of texture types. The texture type is based on several parameters and each texture type includes several reference spectral signatures. The processor is further configured to generate spectral signatures of the surface and determine the texture of the surface from the spectral signatures. The system further includes memory circuitry configured to store a plurality of reference texture images, each reference texture image having a corresponding reference spectral signature.

[0009] The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 is a block diagram of an illustrative embodiment of a texture identification system;

[0011] FIG. 2 is a flow chart of one of an illustrative embodiment of a method for determining a texture of an object;

[0012] FIG. 3 is a flow chart of one illustrative embodiment of a method for determining a texture of the object from frequency spectrums;

[0013] FIG. 4 shows an example graph depicting a frequency spectrum representative of a tilt angle variation;

[0014] FIG. 5 shows an example graph depicting a frequency spectrum representative of an orientation angle variation;

[0015] FIG. 6 is a block diagram of an illustrative embodiment of a computing device that may be arranged in accordance with the present disclosure;

[0016] FIG. 7 is an illustrative embodiment of a method for textile retrieval;

[0017] FIG. 8 is an illustrative embodiment of a method for textile segregation;

[0018] FIG. 9 is an illustrative directional histogram;

[0019] FIG. 10 is an illustrative embodiment of a method converting a wavelet transformed image to a spherical coordinate system;

[0020] FIG. 11 is an illustrative example of images that may be contained in a textile texture database;

[0021] FIG. 12 is an illustrative directional histogram and corresponding textile texture image;

[0022] FIG. 13 is another illustrative directional histogram and corresponding textile texture image;

[0023] FIG. 14 is an illustrative spectral signature plot;

[0024] FIG. 14 is another illustrative spectral signature plot;

[0025] FIG. 16 is another illustrative spectral signature plot; and

[0026] FIG. 17 is another illustrative spectral signature plot.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0027] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented herein. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, separated, and designed in a wide variety of different configurations, all of which are explicitly contemplated herein.

[0028] Example embodiments are generally directed to determining a texture of an object. The following description is with reference to texture determining applications as used in industries such as the textile industry, however it should be understood that the techniques described herein may be applied in various other applications used in the tiles industry, crystal industry and the like.

[0029] FIG. 1 is a block diagram of an illustrative embodiment of a texture identification system **100**. As depicted, the texture identification system **100** includes a processor **110**, a memory **120** and a display unit **130**. FIG. 1 further depicts an image sensor **140** and an object **150**. The depicted components are described in further detail below.

[0030] The processor **110** may be configured to access an image of the object **150**. In one embodiment, the image is a two dimensional representation of a surface **160** of the object. Examples of the object **150** include fabrics, carpets, tiles, crystals and the like. Depending on the implementation, the processor **110** may be a microprocessor or Central Processing Unit (CPU). In other implementations, the processor **110** may be an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA), a digital signal processor (DSP), or other integrated formats.

[0031] The image sensor **140** may be configured to capture an image of the object **150**. In one embodiment, the image sensor **140** is a digital camera. It may be noted that the processor **110** may be configured to access the image from the image sensor **140**, the memory **120** or from an external memory device (not shown).

[0032] The memory **120** may be configured to maintain (e.g., store) reference images with corresponding reference texture information. In one embodiment, each reference image is represented in the form of reference spectral signatures. In a further embodiment, the various reference images stored in the memory **120** are classified into a corresponding texture type. As used herein, a reference spectral signature corresponds to texture signatures extracted from the frequency spectrum of the reference image.

[0033] The memory **120** may include hard disk drives, optical drives, tape drives, random access memory (RAM), read-only memory (ROM), programmable read-only memory (PROM), redundant arrays of independent disks (RAID), flash memory, magneto-optical memory, holographic memory, bubble memory, magnetic drum, memory stick, Mylar® tape, smartdisk, thin film memory, zip drive, or the like or any combination thereof.

[0034] The processor **110** may be configured to calculate one or more parameters of the image of the object. Examples of these parameters include directionality of the image, homogeneity of the image, regularity of the image and roughness of the image. The parameters are used to classify the surface into a texture type from an available set of texture types.

[0035] In one embodiment, there are four texture types. Each texture type includes several reference images and its corresponding texture information. As used herein, a reference image is a two dimensional representation of an example object and the texture information includes information regarding the texture of the example object. As described above, each reference texture has corresponding reference spectral signatures.

[0036] The processor **110** may also be configured to generate spectral signatures from the image. In general, spectral signatures are the specific combination of reflected and absorbed electromagnetic (EM) radiation at varying wavelengths which can uniquely identify an object. For example, the spectral signature of stars indicates the spectrum according to the EM spectrum. The spectral signature of an object is a function of the incidental EM wavelength and material interaction with that section of the electromagnetic spectrum. Typically, measurements may be made with various instruments, including a task specific spectrometer. As used herein, a spectral signature corresponds to texture signatures extracted from the frequency spectrum of the image of the object. By analyzing the spectral signatures and comparing the spectral signatures of the image with the reference spectral signatures stored in the memory, the texture of the surface of the object **150** may be determined. The manner in which the texture of the object **150** is determined in described in further detail below.

[0037] The texture description and retrieval methods and system described herein may be used both in texture information based indexing and retrieval of one or more images. In one embodiment, textile texture images may be stored in a database, the corresponding data texture descriptors may also be generated and stored in the database. When a query textile texture image is entered into such a database, one or more query data texture descriptors associated with the query textile texture image may be generated and compared with the data texture descriptors stored in the database in order to perform retrieval of a matching textile image. Such matching may be based on determining the data texture descriptors in the database that are closest or most similar to the query data texture descriptors.

[0038] FIG. 7 illustrates a non-limiting example method **700** for implementing a textile retrieval system according to an embodiment of the present disclosure. At block **701**, a query textile texture image may be entered into a textile retrieval system. The type of texture may be segregated at block **702**. In one embodiment, when the query textile texture is entered into the retrieval system, several texture features, such as directionality, homogeneity, regularity and roughness, may be extracted or determined. At block **702**, the entered query textile texture image may be segregated into any one of these texture feature categories or types. Note that for textile texture images stored in such a textile retrieval system at block **708**, similar actions may be performed at block **709**.

[0039] The type of query textile texture image may be compared to those contained in a database of the textile retrieval system. At block **710**, the query textile texture image and/or it associated query data texture descriptors may be compared to the textile texture images and/or data texture descriptors in the database. Note that the texture segregation process may be on-demand, and thus performed at block **709** for textile texture images stored in such a textile retrieval system as needed, for example when a query is entered.

[0040] At block **711**, upon finding a matching textile texture image and/or data texture descriptors in the database, one or more wavelets may be chosen for the matching textile texture images. Likewise, at block **703**, wavelets may be chosen for the query textile texture image. At blocks **704** and **712**, affine invariant texture signatures may be extracted from the query textile texture image and the matching textile texture image, respectively. Similarity measurement may be performed comparing the query textile texture image and the matching textile texture image at block **705**. At block **706**, the relevant matching textiles are retrieved.

[0041] FIG. 8 illustrates a non-limiting example method **800** for performing texture segregation, for example, at blocks **702** and **709** of FIG. 7. At block **801**, a textile texture image may be provide or received as input. At block **802** (which, in one embodiment, may be performed in parallel with the activities performed at block **803**, **804**, and/or **805**), the directionality of the textile texture image may be determined. Directionality is a significant texture feature and may be well-perceived by a human visual system. In one embodiment, the geometric property of the directional histogram may be used to calculate the directionality of an image. To calculate the directionality histogram, which may be denoted as HD, the gray scale image may be convoluted with any horizontal and vertical edge operators. For a particular pixel of an image, the outputs of the horizontal and vertical operations may be identified as ∇H and ∇V, respectively. Then a gradient vector for the pixel may be calculated with following formulae:

Magnitude □ □ of □ □ vector □ : □ □ □ ∇ G □ = □ ∇ H □ + □ ∇ V □ 2 Angle □ □ of □ □ vector □ : □ □ θ = tan - 1 □ (∇ V ∇ H)

[0042] HD may then be calculated by quantizing θ and counting the number of pixels with a magnitude greater than a threshold. Next, all peaks and valleys in HD may be identified. In one embodiment, if there are np peaks in the histogram, for each peak p, let wp be the set of bins from its previous valley to its next valley, and let φp be the angular position of the peak. wp may be considered as a hill whose peak is p. In such an embodiment, let HD(φ) be the height of a bin at angular position φ.

[0043] In the normalized directional histogram the angles may be represented in the horizontal axis. The angles in the range of −90° to +90° may be divided into 12 intervals and the quantized angles may be −75°, −60°, −45°, . . . , +90°. The vertical axis may represent the percentage of pixels with different gradient angles. The edges oriented at −90° are the same as edges oriented +90°. If the angles are placed in a circle as depicted in histogram **900** shown in FIG. 9, the next angle of −75° in anti-clockwise direction may be +90°. Thus the histogram may be constructed starting from any angle. By considering the circular nature of bins, the position effect may be removed.

[0044] Further at block **802**, the sharpness of each hill in the histogram may be calculated from geometric slope of each hill. The sharpness of the hill may be then calculated as the weighted sum of slopes of all line segments joining bin tops using the following:

Sharpness of hill=$\Sigma_{\text{weight } u}$×slope$_u$+$\Sigma_{\text{weight } \times \text{slope}}$

where the weight of the slope may be obtained from:

□ weight ik = 2 - i + 1 , □ □ where □ i = circular □ □ Difference □ □ (peakpos , bin k □ pos) ? □ □ difference □ □ between □ □ □ two □ □ bin □ □ positions . □ ? □ indicates text missing or illegible when filed

[0045] Then, the directionality of the textile texture image may be determined using:

□ directionality = ∑ for □ □ each □ □ hillh □ ? × ? ? □ indicates text missing or illegible when filed

where:

□ weight i = bin □ □ Height □ (peak i) ∑ for □ □ each □ □ hill - h □ bin □ □ Height □ (?) . □ ? □ indicates text missing or illegible when filed

[0046] At block **805** of FIG. 8, (which, in one embodiment, may be performed in parallel with the activities performed at block **802**, **803**, and/or **804**), the homogeneity of the textile texture image may be determined. Homogeneity is one of the Haralick features obtained based on cooccurence matrices of greyscale images. The Grey Level Cooccurence Matrix (GLCM) may be constructed from the textile texture image by estimating the pairwise statistics of pixel intensity. Each element (i,j) of such a matrix may represent an estimate of the probability that two pixels with a specified separation have grey levels i and j. The separation may be specified by a displacement, d and an angle, θ:

$$GLCM,\varphi(d,\theta)=[(i,j|d,\theta)]$$

where φ(d,θ) may be a square matrix of side equal to the number of grey levels in the image and may not be symmetric. Symmetry may be introduced by effectively adding the GLCM to it's transpose and dividing every element by 2. This may render φ(d,θ) and φ(d,θ+180°) identical and makes the GLCM unable to detect 180° rotations. Thus, homogeneity may be given by:

□ H = ∑ i , j □ 1 1 + (i - j) 2 □ ? □ (i , j) ? □ indicates text missing or illegible when filed

[0047] For any choice of d and θ, a separate GLCM may be obtained that may be sensitive to the value of d and θ. The GLCM may be implemented with some degree of rotation invariance. This may be achieved by combining the results of a subset of angles. If the GLCM is calculated with symmetry, then only angles up to 180° may need to be considered and the four angles (0°, 45°, 90°, 135°) may be effective choices. The results may be combined by averaging the GLCM for each angle before calculating the features or by averaging the features calculated for each GLCM.

[0048] At block **803** of FIG. 8, (which, in one embodiment, may be performed in parallel with the activities performed at block **802**, **804**, and/or **805**), the regularity of the textile texture image may be determined. Regularity may be obtained from the projection function. Let F(u,v) be the Fourier version of original image f(x,y), and let F(ρ,θ) be the wavelet transform of the projection of f(x,y) onto a line at an angle θ. Conversion in polar form may be performed as follows:

ρ=√{square root over ((u^2 +v^2))}

$$\theta=\tan^{-1}(v/u)$$

Here, ρ, θ, u, u represents the locations.

[0049] Because the frequency distribution (spectrum magnitude as the probability of the corresponding frequency) may provide a description of texture periodicity, we may calculate the central moment as follows:

C □ (θ) = ∑ ρ □ (ρ - ρ _) □ W □ (ρ , θ)

where ρ may be the mean value of ρ. C(θ) may measure the periodicity of texture regularity. The power spectrum may provide a measurement of the amplitude of texture regularity, and may therefore be used to calculate the regularity of texture.

[0050] At block **804** of FIG. 8, (which, in one embodiment, may be performed in parallel with the activities performed at block **802**, **803**, and/or **805**), the roughness of the textile texture image may be determined. The roughness of the texture can be calculated from the root mean square as:

s q = 1 MN □ ∑ K = 0 M - 1 □ ∑ L = 0 N - 1 □ [z □ (x k □ y k) - μ] 2

where μ may be the mean value of the height, across all in-plane coordinates of image. μ may be obtained using:

μ = 1 MN □ ∑ K = 0 M - 1 □ ∑ L = 0 N - 1 □ Z □ (X k , Y k)

[0051] Note that this method of determining roughness may have a limitation in that roughness may be computed indiscriminately towards the polarity of the height value at a given pixel, relative to the mean height value across all the pixels in the image. The result may be that the roughness may measure nearly the same for two different surfaces, for example, a flat surface with many holes and a flat surface with many peaks. To distinguish different kind of surfaces, another parameter may be calculated to obtain the roughness of texture called the skewness parameter. Skewness S_{sk} may be obtained by:

S sk = 1 MN □ □ S q 2 □ ∑ i = 0 M - 1 □ ∑ i = 0 N - 1 □ [z □ (x k , y k) - μ] 2

[0052] This formula is similar to the root mean square formula, but unlike rms (roughness), skewness S_{sk} may take on positive and negative values as well as zero (even if the surface is not perfectly smooth), because each term in the double summation is raised to an odd power. After calculation of the above mentioned features for a textile texture image, the results may be interpreted at block **806** of FIG. 8, and the textile texture image may be segregated into any one of the above mentioned categories at block **807**.

[0053] Referring again to FIG. 7, and specifically to blocks **703** and **711**, one or more wavelets may be chosen for a textile texture image. One wavelet that may be chosen is a Daubechies wavelet, which may be selected from the Daubechies wavelet that are a family of orthogonal wavelets defining a discrete wavelet transform and characterized by a maximal number of vanishing moments for some given support. With each wavelet type in this family of wavelets, there may be a scaling function (also called father wavelet) that generates an orthogonal multi-resolution analysis. The wavelet coefficients may be derived by reversing the order of the scaling function coefficients and then reversing the sign of every second scaling function coefficients. These wavelets have no explicit expression except for db1, which is the Haar wavelet.

[0054] Another wavelet that may be chosen is a Mexican Hat wavelet. A Mexican Hat wavelet may be defined as the second derivative of a Gaussian probability distribution function. This transform may be used to obtain a good retrieval rate for isotropic textures. The scaling coefficients for the Mexican Hat wavelet transform may be obtained as follows:

$$S(x)=c^*e^{(-x^2/2)}(1-x^2)$$

where the constant c is:

c = 2 ∏ 1 / 4 □ 3

The wavelet coefficients may be derived by reversing the order of the scaling function coefficients and then reversing the sign of every second scaling function coefficients.

[0055] Another wavelet that may be used is a Gabor wavelet. A Gabor filter is a linear filter whose impulse response i may be defined by a harmonic function multiplied by a Gaussian function. A Gabor wavelet, with width parameter w and frequency parameter v, may be represented as the following analyzing wavelet:

$$\Psi(X)=W^{-1/2\ -\pi(X/W)\ 2\ t2\pi VX/\ W}$$

The wavelet is complex valued. Its real part may be:

$$\Psi_R(X)=W^{-1/2\ -\pi(X/W)\ 2}\cos(2\pi VX/W)$$

and its imaginary part may be:

$$\Psi_I(X)=W^{-1/2\ -\pi(X/W)\ 2}\sin(2\pi VX/W)$$

The width parameter w may play the same role as it does for the Mexican hat wavelet. w may control the width of the region over which most of the energy of Ψ(X) is concentrated. The frequency parameter v may provide the Gabor wavelet with an extra parameter for analysis.

[0056] Another wavelet that may be used, in one embodiment as an alternative to the Gabor wavelet, is the log-Gabor wavelet. Natural images may be better coded by filters that have Gaussian transfer functions when viewed on the logarithmic frequency scale. Gabor functions may have Gaussian transfer functions only when viewed on the linear frequency scale. On the linear frequency scale the log-Gabor function has a transfer function of the form:

$$G(W)=e^{(-\log(W/W\ 0)\ 2\ /\ \log(K/W\ 0)\ 2)}$$

where w_0 may be the filter's center frequency. To obtain constant shape ratio filters, the term K/w_0 may also be held constant for varying w_0. Each of the wavelets are described herein may be applied for different types of textures, and the best wavelet for a particular type of texture may be identified based on the retrieval of such a texture from a database as described.

[0057] FIG. 2 is a flow chart one of an alternative embodiment of a method **200** for determining a texture of an object. The method **200** in FIG. 2 may be implemented using, for example, the texture identification system **100** discussed above. The method **200** may include one or more operations, actions, or functions as illustrated by one or more of blocks **210**, **220**, **230**, **240** and/or **250**. Although illustrated as discrete blocks, various blocks may be divided into additional blocks, combined into fewer blocks, or eliminated, depending on the desired implementation. Processing may begin at block **210**.

[0058] At block **210**, a texture identification system may receive an image of an object whose texture is to be determined. Processing may continue from block **210** to block **220**.

[0059] At block **220**, the texture identification system may calculate various parameters of the image. The parameters are descriptors of the texture of the object. For example, a directionality parameter may be calculated to indicate the direction of the texture, for example, vertical, horizontal, diagonal, etc. A homogeneity parameter may be calculated to indicate if the texture of the object is the same throughout the surface. A regularity parameter may be calculated to indicate whether the texture of the object is regular (that is, to indicate the regularity of the texture). A roughness parameter may be calculated to indicate whether the texture is rough or smooth (that is, to indicate the roughness or smoothness of the texture).

[0060] Several techniques may be employed to determine the various parameters of the image. For example, a directionality parameter of the image may be obtained by generating a directional histogram. The directional histogram of the image may be based on a gray scale value of each pixel in the image. The directionality parameter may be determined by calculating the number of peaks in the histogram. The directionality parameter provides an estimate of whether the texture of the object is aligned in a specific direction.

[0061] Similarly, a homogeneity parameter of the image may be obtained by generating a co-occurrence matrix of the image. A co-occurrence matrix is a representation of the occurrence of each pixel in the image with respect to its surrounding pixels. In one embodiment, a grey level co-occurrence matrix (GLCM) is constructed from the image by estimating the pair wise statistics of pixel intensity. The co-occurrence matrix provides an estimate of whether the surface of the object is homogeneous.

[0062] A regularity parameter of the image may be obtained by first representing the image in a frequency domain and then analyzing the frequency spectrum of the image. The frequency spectrum is analyzed using mathematical models to determine texture periodicity which in turn reflects the regularity of the surface of the object.

[0063] Similarly, a roughness parameter of the image may be determined by calculating a root mean scare value for the image. The root mean square value is a sum of the variation of each pixel value (intensity value) with reference to a mean pixel value. The root mean square value provides an estimate of the roughness of the surface of the object. Note that any of these parameters may be calculated as described above, or alternate means or methods may be used to determine such parameters. All such embodiments are contemplated as within the scope of the present disclosure.

[0064] Processing may continue from block **220** to block **230** where the surface may be classified, or segregated, into at least one texture type from a set of available texture types. In a specific embodiment, the surface may be classified into a single texture type. Examples of available texture types include homogenous textures, directional textures, regular textures and rough textures. The texture type is based on several parameters. Further, each texture type includes several reference images. Processing may continue from block **230** to block **240**.

[0065] At block **240**, a frequency spectrum of the image may be generated. In one embodiment, to generate a frequency spectrum, the image may first be converted into a frequency domain using a transform function. In one embodiment, the transform function may be selected based on the texture type of the image. Examples of transform functions include Fourier transforms and wavelet transforms. In one embodiment, a 3D Fourier transform is used. Examples of wavelet transforms include Daubechies wavelets, Mexican Hat wavelets, Gabor wavelets and Log Gabor wavelets, as described herein. Any other wavelets may be used, and all such wavelets are contemplated as within the scope of the present disclosure. Processing may continue from block **240** to block **250**.

[0066] At block **250**, the texture of the surface may be determined by extracting the spectral signatures from the frequency spectrum. A texture value may be computed from the spectral signatures. The texture value may be computed by comparing the spectral signatures with the reference spectral signatures. Each comparison generates a corresponding texture value. In one embodiment, the texture may be determined based on comparison that generates the minimum texture value.

[0067] The spectral signatures generated are based on a specific characteristic of the image. When the image appears to be rotated, a spectral signature for a rotation parameter is generated. Similarly, when the image is scaled, spectral signatures for a scaling parameter and a translation parameter are generated. The manner in which a spectral signature for a rotation parameter is computed is described in further detail below.

[0068] FIG. 3 is a flow chart of an illustrative embodiment of a method **300** for determining a texture of the object from frequency spectrums. As one part of this method, as mentioned above, the texture may initially be projected into a 3D Cartesian co-ordinate system. The method **300** in FIG. 3 may be implemented using, for example, the texture identification systems and methods discussed above. The method **300** may include one or more operations, actions, or functions as illustrated by one or more of blocks **310**, **320**, **330**, **340** and/or **350**. Although illustrated as discrete blocks, various blocks may be divided into additional blocks, combined into fewer blocks, or eliminated, depending on the desired implementation. Processing may begin at block **310**.

[0069] At block **310**, a two-dimensional image representative of a surface of an object is received. In one embodiment, the image is rotated. Processing may continue from block **310** to block **320**.

[0070] At block **320**, a three-dimensional (3D) projection of the image is estimated. In one embodiment, the projection is estimated using an intensity value, a tilt angle and an orientation angle.

[0071] In one embodiment, the 3D projection is obtained by projecting the two dimensional image onto a Cartesian coordinate system. For example, consider an image represented generally as I(x, y) with a total number of 'M' pixels, a tilt angle represented by 'α' and an orientation angle 'β'. When the image is projected on to a Cartesian plane of f(x, y, z), it may be represented as:

$x=M\sin\beta\cos\alpha$ Equation (1)

$y=M\sin\beta\sin\alpha$ Equation (2)

$z=M\cos\beta$ Equation (3)

[0072] Processing may continue from block **320** to block **330** where the 3D projection is transformed into a frequency domain. In one embodiment, a 3D Fourier transform is used for the transformation. Thus for the image projection f(x, y, z) in the Cartesian co-ordinate system, the three dimensional Fourier transform F(u,v,w) is represented by:

$F(u,v,w)=\iiint f(x,y,z)\exp(-j2\pi(ux+vy+wz))dxdydz$ Equation (4)

[0073] In one embodiment, $f_r(x_r, y_r, z_r)$ may be the rotated version of f(x, y, z). In such an embodiment, the relationship of these two images may be formulated as follows:

f r (x r , y r , z r) = f (x , y , z) [x r y r z r] = [R 11 R 12 R 13 R 21 R 22 R 23 R 31 R 32 R 33] [x y z]

where R is the orthogonal matrix. When the original texture is rotated by an angle, the frequency spectrum may also be rotated by the same, demonstrating the rotation property of the Fourier transform.

[0074] Processing may continue from block **330** to block **340** where the 3D projection in the frequency domain is projected on to a spherical co-ordinate system. In general, the spherical coordinates of a point 'P' are defined by 'ρ', 'θ' and 'Φ'. In general, 'ρ' represents the radius or radial distance from the origin 'O' to point 'P', the inclination (or polar angle), 'θ' is the angle between the zenith direction and the line segment connecting origin 'O' to point 'P' and 'Φ' represents the azimuth angle measured from the azimuth reference direction to the orthogonal projection of the line segment OP on a reference plane.

[0075] Thus, F(u,v,w) may be projected on to a spherical coordinate system at angles 'θ' and 'Φ'. The Fourier transform of such a projection may be F(ρ,θ,Φ), where:

ρ=√{square root over $((u^2+v^2+w^2))$} Equation (5)

$\Phi=\tan^{-1}(v/u)$ Equation (6)

$\theta=\cos^{-1}$(w/√{square root over $((u^2+v^2+w^2))$}) Equation (7)

and $F_r(\rho_r,\theta_r,\Phi_r)$ may be the Fourier transform of $f_r(x_r, y_r, z_r)$ projected onto a plane at angles θ_r and Φ_r. The relationship between the rotated and unrotated image in spherical form may be represented as $F_r(\rho_r,\theta_r,\Phi_r)=F(\rho,\theta,\Phi)$.

[0076] Processing may continue from block **340** to block **350** where the texture of the surface is determined. In one implementation, the texture of the surface may be determined by analyzing spectral signatures extracted from the 3D projection on the spherical co-ordinate system. The frequency spectrums are generated for the tilt angle variation, the orientation angle variation, and the spectral signatures may be extracted. Since the frequency distribution (spectrum magnitude as the probability of the corresponding frequency) may provide a description of texture periodicity, the central moment of $F_r(\rho_r,\theta_r,\Phi_r)$ and F(ρ,θ,Φ) may be calculated both for θ and Φ using the following equations:

C r (θ) = ∑ ρ r (ρ r - ρ _ r) F (ρ r , θ r , Φ r) Equation (8) C (θ) = ∑ ρ (ρ - ρ _) F (ρ , θ , Φ) Equation (9) C r (Φ) = ∑ ρ r (ρ r - ρ _ r) F (ρ r , θ r , Φ r) Equation (10) C (Φ) = ∑ ρ (ρ - ρ _) F (ρ , θ , Φ) Equation (11)

where ' ρ', and ρ_r may be the mean values of ρ and ρ_r. Equations 8-11 may be used to measure of a periodicity of the texture using C(θ), $C_r(\theta)$, C(Φ), and $C_r(\Phi)$.

[0077] The power spectrum may provide a measurement of the amplitude of texture regularity. Thus, it may be used to compute the spectral signatures at angles θ and $\theta_r=\theta+\Delta\theta$ as follows:

T r □ (θ) = C r □ (θ r) □ ∑ ρ r □ F r □ (ρ r , θ r , Φ r) Equation □ □ (12) T □ (θ) = C □ (θ) □ ∑ ρ □ F □ (ρ , θ , Φ) Equation □ □ (13) T r □ (Φ) = C r □ (Φ r) □ ∑ ρ r □ F r □ (ρ r , θ r , Φ r) Equation □ □ (14) T □ (Φ) = C □ (Φ) □ ∑ ρ □ F □ (ρ , θ , Φ) Equation □ □ (15)

such that the orientation spectral Signatures T(θ), $T_r(\theta)$, T(Φ) and $T_r(\Phi)$ are obtained. The texture signature may be rotation dependent and it may be a periodic function of θ and Φ with a period of 2Π.

[0078] If T(θ) and T(Φ) are computed from f(x, y, z) and $T_r(\theta)$ and $T_r(\Phi)$ are computed from $f_r(x_r, y_r, Z_r)$ rotated by Δθ and ΔΦ from f(x, y, z), T(θ) may be equal to $T_r(\theta)$ if $\theta_r=\theta+\Delta\theta$. Similarly T(Φ) may be equal to $T_r(\Phi)$ $\Phi_r=\Phi+\Delta\Phi$. Thus a rotation of the input image f(x, y, z) by Δθ and ΔΦ may be equivalent to a translation of its spectral signatures by the same amount along the orientations. Since the Fourier magnitude is invariant to translation, the Fourier expansion of T(θ) and T(Φ) may provide a set of rotation invariant features for the input image I(x, y).

[0079] FIG. 4 shows an example graph **400** depicting a frequency spectrum representative of a tilt angle variation. The graph **400** shows the distribution of the tilt angle variation for an example two-dimensional image. The x-axis represents a tilt angle 'θ' and the y-axis represents T(θ). As discussed above, T(θ) is a representative of a tilt angle variation. In one embodiment, T(θ) is obtained using equation (13).

[0080] FIG. 5 shows an example graph **500** depicting a frequency spectrum representative of an orientation angle variation. Graph **500** shows the distribution of the orientation angle variation for the example two-dimensional image whose frequency spectrum representative of the tilt angle variation is shown in FIG. 4. The x-axis represents an orientation angle 'φ' and the y-axis represents T(φ). As discussed above, T(φ) is a representative of an orientation angle variation. In one embodiment, T(φ) is obtained using equation (15).

[0081] In order to determine the texture of the surface, both spectral signatures are compared with corresponding reference spectral signatures of the reference images stored in the memory. The reference spectral signatures can be generated using one or more of equations (1) to (15) as described in FIG. 3.

[0082] In one embodiment, the spectral signature for the tilt angle variation is compared with several reference spectral signatures for tilt angle variation. Similarly, the spectral signature for the orientation angle variation is compared with several reference spectral signatures for orientation angle variation.

[0083] In one embodiment, a tilt angle value is calculated based on a sum of peak to peak distance between the spectral signature for the tilt angle variation and the reference spectral signature for the tilt angle variation. Thus, a tilt angle value is generated for each comparison.

[0084] Similarly, an orientation angle value is calculated based on a sum of peak to peak distance between the spectral signature for the orientation angle variation and the reference spectral signature for the orientation angle variation. Thus, a slant angle value is calculated for each comparison.

[0085] A texture value based on the tilt angle value and the orientation angle value is then generated for each comparison. In one embodiment, the texture value is he sum of the tilt angle value and the orientation angle value. The texture of the object is determined based on the reference spectral signatures that produce the minimum texture value.

[0086] Referring again to FIG. 7, and specifically to blocks **704** and **712**, affine invariant texture signatures may be extracted from the textile texture images according to the disclosed embodiments. A textile texture image, such as a query textile texture image, may be a scaled, translated, and rotated (image and surface) version of the a textile texture image found, for example, in a catalogue. To generate the system invariant to this kind of affine distortions, in one embodiment the platform may be changed to the wavelet domain. A two-dimensional (2D) wavelet may contribute information for a simple image rotation, scale, and translation, but to incorporate the surface rotation (tilt (theta) and orientation (phi) changes), a three-dimensional (3D) wavelet transform may be utilized.

[0087] FIG. 10 illustrates non-limiting example method **1000** for converting a wavelet transformed image to a spherical coordinate system so that the variations of tilt and orientation changes may be captured. At block **1001** a textile texture image may be provided or received. A 3D wavelet transform may be used to generate a power spectrum a block **1002**. Projection may then be used to generate a scalogram at block **1003**. Next, a Fourier transform may be used to determine affine invariant features at block **1004**.

[0088] In an embodiment, W(ρ, θ, φ) may be the wavelet transform of the projection of f(x, y, z) onto a plane at angles θ and φ, where:

ρ = (u 2 + v 2 + w 2) Φ = tan - 1 □ (v / u) θ = tan - 1 (u 2 + v 2 w)

and $W_a(x_a, y_a, z_a)$ may be the projection of $f_a(x_a, y_a, z_a)$ onto a plane at angles θ_a and φ_a. The relationship between the original and affine distorted image in polar form may be represented as:

$$W_a(\rho_a,\theta_a,\Phi_a)=W(\rho,\theta,\Phi)$$

Since the frequency distribution (spectrum magnitude as the probability of the corresponding frequency) may provide a description of texture periodicity, the central moment may be calculated as follows:

C a □ (θ) = ∑ ρ a □ (ρ a , ρ _ a) □ W □ (P a , θ a , Φ a) C □ (θ) = ∑ ρ □ (ρ - ρ _) □ W □ (ρ , θ , Φ) C a □ (Φ) = ∑ ρ a □ (ρ a - ρ _ a) □ W □ (ρ a , θ a , Φ a) C □ (Φ) = ∑ ρ □ (ρ - ρ _) □ W □ (ρ , θ , Φ)

where ρ and ρ $_a$ are the mean value of ρ and $ρ_a$. C(θ) may measure the periodicity of texture regularity, and C_a(θ), C(φ) and C_a(Φ) may be similarly calculated.

Note that the power spectrum may provide a measurement of the amplitude of texture regularity. Thus, the power spectrum may be taken into account to compute the signatures at angle θ and $θ_a$=θ+Δθ as follows:

T a □ (θ) = C a □ (θ) □ ∑ ρ a □ W a □ (ρ a , θ a , Φ a) T □ (θ) = C □ (θ) □ ∑ ρ □ W □ (ρ , θ , Φ) T a □ (Φ) = C a □ (Φ) □ ∑ ρ a □ W a □ (ρ a , θ a , Φ a) T □ (Φ) = C □ (Φ) □ ∑ ρ □ W □ (ρ , θ , Φ)

such that the orientation spectrum signatures T(θ), T_a(θ), T(Φ) and T_a(Φ) may be obtained.

[0089] The texture signature may be affine dependent and may be a periodic function of θ and φ with a period of 2Π. If T(θ) and T(Φ) are computed from f(x, y, z) and T_a(θ) and T_a(Φ) are computed from f_a(x_a, y_a, z_a) affine distorted by Δθ and Δφ from f(x, y, z), T(θ)=T_a(θ) if $θ_a$=θ+Δθ. Similarly results may be seen for T(Φ). Thus, a rotation of the input image f(x, y, z) by Δθ and Δφ may be equivalent to a translation of its scalogram by the same amount along the orientations. The translation between the two plots may be evident; however the plots may share almost the same Fourier magnitude response. Since the Fourier magnitude is invariant to translation, the Fourier expansion of T(θ) and T(Φ) may provide a set of affine invariant features for the input image I(x, y). Note that the above described techniques can be implemented in a computing device as is described below.

[0090] To demonstrate the effect of the embodiments described herein, example, non-limiting results of the various implementations of such embodiments will now be described. FIG. 11 illustrates examples of images that may be contained in a textile texture database. The images illustrated in FIG. 11 are merely examples and are not intended to limit the scope of the present disclosure in any way. In this example, images are captured and stored individually while surfaces are rotated and illuminated in varied conditions. The database as shown in FIG. **11** consists of four synthetic textures and thirty real textures. In terms of a rotation invariant texture classification scheme, this example texture database provides a set of surface rotations and image rotations along with the registered photometric stereo image data. Each texture sample has 40 samples under varying image rotations and surface rotations. Rotations are carried out by an increment of 30° and 45°. Also the database may contain scaled and translated version of the original texture.

[0091] Directionality may be a significant texture feature that is well perceived by the human visual system. The geometric property of the directional histogram may be used to calculate the directionality of the image, as shown in FIG. 12, where a directional histogram is illustrated for image “An**2**” shown in FIG. 11. The directionality of the textile texture “An**2**” as shown in FIG. 12 is 46%. “An**2**” is an isotropic texture.

[0092] FIG. 13 illustrates a directional histogram for image “Im**2**” of FIG. 11. The directionality of this texture is 98%. The hill in the directional histogram may be referred to the set of bins from the previous valley to the next valley. The number of hills for the texture image “An**2**” seen in FIG. 12 is four, as can be seen in its directional histogram, whereas the texture image “Im**2**” has a single hill in its corresponding histogram as seen in FIG. 13. Thus it may be inferred that lesser the number of hills, the higher the directionality.

[0093] FIG. 14 illustrates a spectral signature plot that shows the results of using a Fourier transform of a scalogram signature by varying theta using a log Gabor wavelet. Chart **1401** illustrates the Fourier expansion of the spectrum signature of the original image as compared to angle theta, while chart **1402** illustrates the Fourier expansion of the spectrum signature of the affine distorted image as compared to angle theta.

[0094] FIG. 15 illustrates a spectral signature plot that shows the results of using a Fourier transform of a scalogram signature by varying phi using a log Gabor wavelet. Chart **1501** illustrates the Fourier expansion of the spectrum signature of the original image as compared to angle phi, while chart **1502** illustrates the Fourier expansion of the spectrum signature of the affine distorted image as compared to angle phi.

[0095] FIG. 16 illustrates a spectral signature plot that shows the results of using a Fourier transform of a scalogram signature by varying theta using a Daubechies wavelet. Chart **1601** illustrates the Fourier expansion of the spectrum signature of the original image as compared to angle theta, while chart **1602** illustrates the Fourier expansion of the spectrum signature of the affine distorted image as compared to angle theta.

[0096] FIG. 17 a spectral signature plot that shows illustrates the results of using a Fourier transform of a scalogram signature by varying phi using a Daubechies wavelet. Chart **1701** illustrates the Fourier expansion of the spectrum signature of the original image as compared to angle phi, while chart **1702** illustrates the Fourier expansion of the spectrum signature of the affine distorted image as compared to angle phi.

[0097] From these results, it can be inferred that the Fourier expansion of a scalogram of an original and an affine distorted image remains similar, since the shift in peak is compensated by Fourier transform based on its affine invariant property. Based on the results obtained, it can further be inferred that log Gabor wavelets may provide a better retrieval result for directional type query image than other wavelet transforms. The values of all the performance evaluation measures for 20, 40, 60, 80 and 100 retrievals using a 3D log Gabor wavelet transform for directional texture are illustrated below in Table 1.

TABLE 1

Performance using 3D Log Gabor wavelet for Directional textile Texture

	Retrievals				
	20	40	60	80	100
Precision	1	1	0.982	0.977	0.962
Recall	0.222	0.444	0.677	1	1
Error rate	0	0	0.018	0.023	0.038
Retrieval Efficiency	100	100	98.2	97.7	96.2

[0098] A Mexican hat wavelet may provide good retrieval results for Homogeneous type query image compared to other wavelet transforms. The values of all the performance evaluation measures for 20, 40, 60, 80 and 100 retrievals using a Mexican hat wavelet transform for directional texture are illustrated below in Table 2.

TABLE 2

Performance using 3DMexican hat wavelet for Homogeneous textile Texture

	Retrievals				
	20	40	60	80	100
Precision	1	1	0.95	0.9	0.9
Recall	0.222	0.444	0.633	1	1
Error rate	0	0	0.05	0.1	0.1
Retrieval Efficiency	100	100	95	90	90

[0099] In Table 3, the results of a performance evaluation of various wavelet transforms are tabulated. It may be inferred from these results that the Mexican hat wavelet provides good retrieval efficiency for homogeneous textures. Similarly, log Gabor wavelets may provide good retrieval efficiency for directional and regular texture, while Daubechies and Gabor wavelets may work well for directional textures. Therefore, in some embodiments, the type of wavelet chosen may be based on the type of texture of the query image.

TABLE 3

Performance evaluation of various Wavelet transforms

	Method				
Measure	Daubecheis	Mexican Hat (Homogeneous)	Gabor	Log Gabor (regular)	Log Gabor (directional)
Precision	0.962	0.95	0.955	0.923	0.962
Recall	0.62	0.6598	0.622	1	0.61
Error rate	0.375	0.05	0.045	0.077	0.038
Retrieval Efficiency	96.2	95	95.5	92.3	96.2

TABLE 3

Computational Time	17 s	17 s	17 s	17 s	15 s

[0100] FIG. 6 is a block diagram illustrating an example computing device **600** that may be arranged for determining a texture of an object in accordance with the present disclosure. In a very basic configuration **602**, computing device **600** typically includes one or more processors and a system memory **606**. A memory bus **608** may be used for communicating between processor **604** and system memory **606**.

[0101] Depending on the desired configuration, processor **604** may be of any type including but not limited to a microprocessor (μP), a microcontroller (μC), a digital signal processor (DSP), or any combination thereof. Processor **604** may include one more levels of caching, such as a level one cache **610** and a level two cache **612**, a processor core **614**, and registers **616**. An example processor core **614** may include an arithmetic logic unit (ALU), a floating point unit (FPU), a digital signal processing core (DSP Core), or any combination thereof. An example memory controller **618** may also be used with processor **604**, or in some implementations memory controller **618** may be an internal part of processor **604**.

[0102] Depending on the desired configuration, system memory **606** may be of any type including but not limited to volatile memory (such as RAM), non-volatile memory (such as ROM, flash memory, etc.) or any combination thereof. System memory **606** may include an operating system **620**, one or more applications **622**, and program data **624**. Application **622** may include a texture determining algorithm **626** that is arranged to generate a single fused image from a plurality of images. Program data **624** may include images **628** that are representative of reference objects which may be useful for various applications such as image processing as is described herein. In some embodiments, application **622** may be arranged to operate with program data **624** on operating system **620** such that the texture is determined from the image of the object. This described basic configuration **602** is illustrated in FIG. 6 by those components within the inner dashed line.

[0103] Computing device **600** may have additional features or functionality, and additional interfaces to facilitate communications between basic configuration **602** and any required devices and interfaces. For example, a bus/interface controller **630** may be used to facilitate communications between basic configuration **602** and one or more data storage devices **632** via a storage interface bus **634**. Data storage devices **632** may be removable storage devices **636**, non-removable storage devices **638**, or a combination thereof. Examples of removable storage and non-removable storage devices include magnetic disk devices such as flexible disk drives and hard-disk drives (HDD), optical disk drives such as compact disk (CD) drives or digital versatile disk (DVD) drives, solid state drives (SSD), and tape drives to name a few. Example computer storage media may include volatile and nonvolatile, removable and non-removable media implemented in any method or technology for storage of information, such as computer readable instructions, data structures, program modules, or other data.

[0104] System memory **606**, removable storage devices **636** and non-removable storage devices **638** are examples of computer storage media. Computer storage media includes, but is not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which may be used to store the desired information and which may be accessed by computing device **600**. Any such computer storage media may be part of computing device **600**.

[0105] Computing device **600** may also include an interface bus **640** for facilitating communication from various interface devices (e.g., output devices **642**, peripheral interfaces **644**, and communication devices **646**) to basic configuration **602** via bus/interface controller **630**. Example output devices **642** include a graphics processing unit **648** and an audio processing unit **650**, which may be configured to communicate to various external devices such as a display or speakers via one or more A/V ports **652**. Example peripheral interfaces **644** include a serial interface controller **654** or a parallel interface controller **656**, which may be configured to communicate with external devices such as input devices (e.g., keyboard, mouse, pen, voice input device, touch input device, etc.) or other peripheral devices (e.g., printer, scanner, etc.) via one or more I/O ports **658**. An example communication device **646** includes a network controller **660**, which may be arranged to facilitate communications with one or more other computing devices **662** over a network communication link via one or more communication ports **664**.

[0106] The network communication link may be one example of a communication media. Communication media may typically be embodied by computer readable instructions, data structures, program modules, or other data in a modulated data signal, such as a carrier wave or other transport mechanism, and may include any information delivery media. A “modulated data signal” may be a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media may include wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, radio frequency (RF), microwave, infrared (IR) and other wireless media. The term computer readable media as used herein may include both storage media and communication media.

[0107] Computing device **600** may be implemented as a portion of a small-form factor portable (or mobile) electronic device such as a cell phone, a personal data assistant (PDA), a personal media player device, a wireless web-watch device, a personal headset device, an application specific device, or a hybrid device that include any of the above functions. Computing device **600** may also be implemented as a personal computer including both laptop computer and non-laptop computer configurations.

[0108] The present disclosure is not to be limited in terms of the particular embodiments described in this application, which are intended as illustrations of various aspects. Many modifications and variations can be made without departing from its spirit and scope, as will be apparent to those skilled in the art. Functionally equivalent methods and apparatuses within the scope of the disclosure, in addition to those enumerated herein, will be apparent to those skilled in the art from the foregoing descriptions. Such modifications and variations are intended to fall within the scope of the appended claims. The present disclosure is to be limited only by the terms of the appended claims, along with the full scope of equivalents to which such claims are entitled. It is to be understood that this disclosure is not limited to particular methods, reagents, compounds compositions or biological systems, which can, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

[0109] With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity.

[0110] It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as “open” terms (e.g., the term “including” should be interpreted as “including but not limited to,” the term “having” should be interpreted as “having at least,” the term “includes” should be interpreted as “includes but is not limited to,” etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases “at least one” and “one or more” to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles “a” or “an” limits any particular claim containing such introduced claim recitation to embodiments containing only one such recitation, even when the same claim includes the introductory phrases “one or more” or “at least one” and indefinite articles such as “a” or “an” (e.g., “a” and/or “an” should be interpreted to mean “at least one” or “one or more”); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should be interpreted to mean at least the recited number (e.g., the bare recitation of “two recitations,” without other modifiers, means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to “at least one of A, B, and C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “a system having at least one of A, B, and C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to “at least one of A, B, or C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “a system having at least one of A, B, or C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms. For example, the phrase “A or B” will be understood to include the possibilities of “A” or “B” or “A and B.”

[0111] As will be understood by one skilled in the art, for any and all purposes, such as in terms of providing a written description, all ranges disclosed herein also encompass any and all possible subranges and combinations of subranges thereof. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, tenths, etc. As a non-limiting example, each range discussed herein can be readily broken down into a lower third, middle third and upper third, etc. As will also be understood by one skilled in the art all language such as “up to,” “at least,” “greater than,” “less than,” and the like include the number recited and refer to ranges which can be subsequently broken down into subranges as discussed above. Finally, as will be understood by one skilled in the art, a range includes each individual member. Thus, for example, a group having 1-3 cells refers to groups having 1, 2, or 3 cells. Similarly, a group having 1-5 cells refers to groups having 1, 2, 3, 4, or 5 cells, and so forth.

[0112] While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

Patent Citations (5)

Publication number	Priority date	Publication date	Assignee	Title
US6795082B2 *	2001-01-10	2004-09-21	Namco Ltd.	Image generation system, program and image generation method
US7064767B2 *	2002-11-19	2006-06-20	Fujitsu Limited	Image solution processing method, processing apparatus, and program
Family To Family Citations				
JPH04240261A	1991-01-24	1992-08-27	Hitachi Ltd	Image-recognition apparatus and pattern-machining and cutting appaparatus
US6785421B1 *	2000-05-22	2004-08-31	Eastman Kodak Company	Analyzing images to determine if one or more sets of materials correspond to the analyzed images
EP2181433B1 *	2007-07-19	2016-05-18	Disney Enterprises, Inc.	Methods and apparatus for multiple texture map storage and filtering

* Cited by examiner, † Cited by third party

Non-Patent Citations (1)

Title
Haley et al., "Rotation-invariant Texture Classification Using a Complete Space-frequency Model," IEEE Transactions on Image Processing, February 1999, Volume 8, Issue 2, pages 255-269 *

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Publication number	Priority date	Publication date	Assignee	Title
CN102938076A *	2012-08-17	2013-02-20	刘洪海	Fabric plane recognition method based on two visual angles
US20130093768A1 *	2011-10-12	2013-04-18	Yale University	Systems and Methods for Creating Texture Exemplars
US20140333620A1 *	2013-05-09	2014-11-13	Yong-Ha Park	Graphic processing unit, graphic processing system including the same and rendering method using the same
CN105979123A *	2015-03-10	2016-09-28	株式会社理光	Image processing system and image processing method
Family To Family Citations				
US9934590B1 *	2015-06-25	2018-04-03	The United States Of America As Represented By The Secretary Of The Air Force	Tchebichef moment shape descriptor for partial point cloud characterization
CN105803623B *	2016-04-18	2017-08-04	南京航空航天大学	Computer Graphics Recognition Method composite material mesostructure

* Cited by examiner, † Cited by third party, ‡ Family to family citation

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Publication	Publication Date	Title
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Hou et al.	2012	Image signature: Highlighting sparse salient regions
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Petrou et al.	2004	Affine invariant features from the trace transform
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US20130325759A1	2013-12-05	Methods and apparatus for performing transformation techniques for data clustering and/or classification
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US20120301014A1	2012-11-29	Learning to rank local interest points
US20130148860A1	2013-06-13	Motion aligned distance calculations for image comparisons
Horng et al.	2003	Texture feature coding method for texture classification
Saavedra et al.	2010	An improved histogram of edge local orientations for sketch-based image retrieval

Priority And Related Applications

Child Applications (1)

Application	Priority date	Filing date	Relation	Title
US14228606	2010-11-02	2014-03-28	Division	Texture identification

Priority Applications (1)

Application	Priority date	Filing date	Title
US12938193	2010-11-02	2010-11-02	Texture identification

Applications Claiming Priority (2)

Application	Filing date	Title
US12938193	2010-11-02	Texture identification
US14228606	2014-03-28	Texture identification

Legal Events

Date	Code	Title	Description
2011-08-15	AS	Assignment	**Owner name**: THIAGARAJAR COLLEGE OF ENGINEERING, INDIA **Free format text**: ASSIGNMENT OF ASSIGNORS INTEREST;ASSIGNORS:BAMA, B. SATHYA;RAJU, S., DR.;KUMAR, V. ABHAI, DR.;REEL/FRAME:026748/0680 **Effective date**: 20101025
2014-01-09	AS	Assignment	**Owner name**: THIAGARAJAR COLLEGE OF ENGINEERING, INDIA

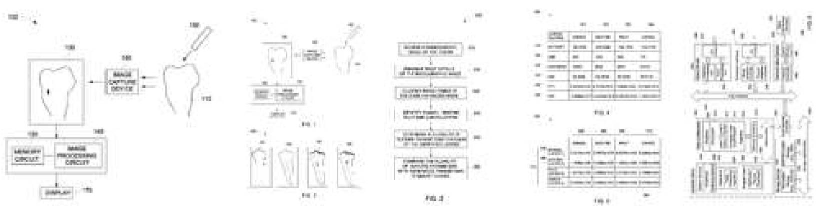
			Free format text: CORRECTIVE ASSIGNMENT TO CORRECT THE NAMES OF THE INVENTORS IN THE ASSIGNMENT DOCUMENT PREVIOUSLY RECORDED ON REEL 026748 FRAME 0680. ASSIGNOR(S) HEREBY CONFIRMS THE ASSIGNMENT OF THE ENTIRE RIGHT, TITLE, AND INTEREST;ASSIGNORS:BALAKRISHNAN, SATHYA BAMA;SRINIVASAN, RAJU;VARADHAN, ABHAIKUMAR;REEL/FRAME:031957/0694 **Effective date**: 20140108
2014-09-09	CC	Certificate of correction	
2017-09-14	MAFP		**Free format text**: PAYMENT OF MAINTENANCE FEE, 4TH YEAR, LARGE ENTITY (ORIGINAL EVENT CODE: M1551) **Year of fee payment**: 4

Dental caries detector

Abstract

Briefly, in accordance with one aspect, a method for detecting caries on a tooth is provided. The method includes clustering image pixels of an edge-enhanced image of the tooth to identify enamel, dentine, pulp and caries layers of the tooth and determining a plurality of texture parameters for each of the identified enamel, dentine, pulp and caries layers. The method also includes comparing the plurality of texture parameters with reference parameters to detect caries on the tooth.

Images (5)



Classifications

A61B6/14 Applications or adaptations for dentistry

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US20110110575A1

US Application

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Priority date : 2009-11-11

Family: US (1) WO (1)

Date	App/Pub Number	Status
2009-12-24	US12647119	Abandoned
2011-05-12	US20110110575A1	Application

Info: Patent citations (15), Cited by (3), Legal events, Similar documents, Priority and Related Applications

External links: USPTO, USPTO Assignment, Espacenet, Global Dossier, Discuss

Claims (20)

1. **1**. A method for detecting caries on a tooth, comprising:

   clustering image pixels of an edge-enhanced image of the tooth to identify enamel, dentine, pulp and caries layers of the tooth;

   determining a plurality of texture parameters for each of the identified enamel, dentine, pulp and caries layers; and

   comparing the plurality of texture parameters with reference parameters to detect caries on the tooth.

2. **2**. The method of claim 1, further comprising:

accessing a radiographic image of the tooth;

high-pass filtering the radiographic image of the tooth to generate the edge-enhanced image; and

labeling the image pixels having similar pixel intensities with a gray level or a color and assigning the labeled image pixels to the enamel, dentine and pulp layers based upon pre-determined thresholds for each of the enamel, dentine and pulp layers.

3. **3**. The method of claim 2, wherein high-pass filtering comprises applying high-pass Butterworth filter to the radiographic image for enhancing edge details of the image.

4. **4**. The method of claim 1, comprising clustering the image pixels via C-means clustering and determining the plurality of texture parameters using gray level co-occurrence matrices of the layers of the edge-enhanced image.

5. **5**. The method of claim 4, wherein the plurality of texture parameters comprise entropy, or angular second moment, or contrast, or inverse different moment, or cluster tendency index, or cluster shade index, or combinations thereof.

6. **6**. The method of claim 1, further comprising assigning different colors to identified layers of the tooth for to permit visualization of the layers.

7. **7**. The method of claim 1, wherein comparing the plurality of texture parameters comprises:

estimating a sum of squared distance based upon the plurality of texture parameters and the reference parameters; and

detecting the caries based upon the estimated sum of squared distance.

8. **8**. The method of claim 1, further comprising determining a depth of the caries by measuring a number of pixels in the caries layer.

9. **9**. A method for detecting caries on a tooth, comprising:

accessing a radiographic image of the tooth;

high-pass filtering the radiographic image to obtain an edge-enhanced image;

clustering image pixels of the edge-enhanced image of the tooth to identify enamel, dentine, pulp and caries layers of the tooth; and

comparing at least one of the entropy, angular second moment, contrast, inverse different moment, cluster tendency index and cluster shade index parameters for each of the identified enamel, dentine, pulp and caries layers with corresponding parameters of respective layers of a reference image to detect the caries on the tooth.

10. **10**. The method of claim 10, wherein clustering image pixels comprises labeling the image pixels having similar pixel intensities with a gray level or a color and assigning the labeled image pixels to the enamel, dentine and pulp layers.

11. **11**. The method of claim 10, further comprising estimating a sum of square distance based upon the at least one of the entropy, angular second moment, contrast, inverse different moment, cluster tendency index and cluster shade index parameters for each of the identified enamel, dentine, pulp and caries layers.

12. **12**. The method of claim 12, further comprising comparing the estimated sum of square distance for each of the enamel, dentine, pulp and caries layers with sum of square distance of corresponding layer of the reference image.

13. **13**. A system for detecting caries on a tooth, comprising:

a memory circuit configured to store a radiographic image of the tooth and reference parameters; and an image processing circuit configured to process the radiographic image to identify enamel, dentine, pulp and caries layers of the tooth and to detect caries on the tooth based upon at least one texture parameter of the enamel, dentine, pulp and caries layers of the tooth and the reference parameters.

14. **14**. The system of claim 13, wherein the image processing circuit is configured to cluster image pixels of the radiographic image via C-means clustering and to estimate the at least one texture parameters using gray level co-occurrence matrices of each of the enamel, dentine, pulp and caries layers.

15. **15**. The system of claim 13, wherein the system comprises:

a X-ray generator for illuminating the tooth; and

an image capture device to capture the radiographic image of the tooth.

16. **16**. The system of claim 13, wherein the texture parameter comprises entropy, angular second moment, contrast, inverse different moment, cluster tendency index and cluster shade index.

17. **17**. The system of claim 13, wherein the image processing circuit is configured to:

estimate a sum of square distance based upon the at least one texture parameter for each of the identified enamel, dentine, pulp and caries layers and the reference parameters; and

differentiate the caries on the tooth based upon the estimated sum of square distance.

18. **18**. The system of claim 13, wherein the image processing circuit comprises a second order Butterworth high-pass filter configured to enhance edge details of the radiographic image.

19. **19**. The system of claim 18, wherein a radius of filter cutoff frequency of the Butterworth high-pass filter is about 0.01.

20. **20**. The system of claim 13, further comprising a display for displaying the processed image with the detected caries on the tooth.

Description

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to Indian Patent Application Serial No. 2760/CHE/2009 filed Nov. 11, 2009, the contents of which are incorporated by reference herein in its entirety.

BACKGROUND

[0002] Dental caries, also known as tooth decay or cavity, is a bacterial disease that occurs on any surface of a tooth that is exposed to the oral cavity. Caries are generally described by their location on tooth surfaces. The location of facial caries is described as buccal when found on the surfaces of posterior teeth opposing the cheeks and as labial when found on the surfaces of anterior teeth opposing the lips. Occlusal caries are found on the chewing surfaces, and lingual caries on surfaces facing the tongue.

[0003] Traditional diagnosis of caries involves inspection of visible tooth surfaces using a light source. Large dental caries are often apparent to the naked eye, but smaller lesions and lesions in early stages are difficult to identify. Further, occlusal and inter proximal caries associated with the existing restorations are much more complicated to detect with clinical examination.

[0004] Typically, a patient is periodically examined using dental radiography to monitor progression of dental caries. A radiograph may be employed to analyze different layers of the tooth to detect the caries on the tooth. Intra oral views, bitewing views and orthopantomography are commonly used radiographs in detection of dental caries. Dental radiographs, obtained using X-rays that are shot through the jaw and picked up on film, may show some cavities before they are visible to the eye. Further, the dentist may assess the extent of the caries lesion using a dental probe. Subsequently, a thermal test may be performed using electric pulp tester to find whether the pulp is affected by the caries or not.

[0005] However, detection using such techniques is usually subjective and may vary in accuracy due to factors such as viewing conditions and dentist expertise, among others. Such techniques are not capable of clinically identifying the abnormalities when the carious lesions are thin or the intrusion of the caries into the pulp is sharp. Further, such systems are not capable of providing other details such as thickness of the enamel and other layers of the tooth and involvement of caries in the respective layers.

SUMMARY

[0006] Briefly, in accordance with one aspect, a method for detecting caries on a tooth is provided. The method includes clustering image pixels of an edge-enhanced image of the tooth to identify enamel, dentine, pulp and caries layers of the tooth and determining a plurality of texture parameters for each of the identified enamel, dentine, pulp and caries layers. The method also includes comparing the plurality of texture parameters with reference parameters to detect caries on the tooth.

[0007] In accordance with another aspect, a method for detecting caries on a tooth is provided. The method includes accessing a radiographic image of the tooth and high-pass filtering the radiographic image to obtain an edge-enhanced image. The method also includes clustering image pixels of the edge-enhanced image of the tooth to identify enamel, dentine, pulp and caries layers of the tooth and comparing at least one of the entropy, angular second moment, contrast, inverse different moment, cluster tendency index and cluster shade index parameters for each of the identified enamel, dentine, pulp and caries layers with corresponding parameters of respective layers of a reference image to detect the caries on the tooth.

[0008] In accordance with another aspect, a system for detecting caries on a tooth is provided. The system includes a memory circuit configured to store a radiographic image of the tooth and reference parameters and an image processing circuit configured to process the radiographic image to identify enamel, dentine, pulp and caries layers of the tooth and to detect caries on the tooth based upon at least one texture parameter of the enamel, dentine, pulp and caries layers of the tooth and the reference parameters.

[0009] The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF THE FIGURES

[0010] FIG. 1 is an example system for detecting caries on a tooth.

[0011] FIG. 2 is an example flow diagram of an embodiment of a method for detecting caries on a tooth using the system of FIG. 1.

[0012] FIG. 3 illustrates example images generated by image processing of a radiographic image of a tooth using the system of FIG. 1.

[0013] FIG. 4 is a table with example values of texture parameters for a caries affected tooth.

[0014] FIG. 5 is a table with example values for estimated sum of square distance obtained by comparing texture parameters for an image with reference parameters of a reference image.

[0015] FIG. 6 is a block diagram illustrating an example computing device that is arranged for detecting caries on a tooth.

DETAILED DESCRIPTION

[0016] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented herein. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the Figures, can be arranged, substituted, combined, separated, and designed in a wide variety of different configurations, all of which are explicitly contemplated herein.

[0017] Example embodiments are generally directed to detection of dental cavities. A dental cavity is also known as a dental caries or tooth decay. The technique provides an automated diagnostic system that processes radiographic images of the tooth and detects dental caries using image segmentation and classification, as will be described in detail below.

[0018] Referring now to FIG. 1, an example system **100** for detecting caries on a tooth **110** is illustrated. As used herein, the term “caries” refers to a decay of tooth structure caused by bacteria and other environmental factors. Examples of forms of caries include but are not limited to holes, grooves, pin point depressions and cracks in the tooth structure. As illustrated, the system **100** includes a memory circuit **120** configured to store a radiographic image **130** of the tooth **110**. The memory circuit **120** is further configured to store reference parameters. In one embodiment, the reference parameters include texture parameters of different layers of tooth of a reference image. It should be borne in mind that, although a single memory circuit is described here, the memory storing function may be performed by more than one memory device associated with the system for storing analysis routines, reference parameters, and so forth.

[0019] The memory circuit **120** may include hard disk drives, optical drives, tape drives, random access memory (RAM), read-only memory (ROM), programmable read-only memory (PROM), redundant arrays of independent disks (RAID), flash memory, magneto-optical memory, holographic memory, bubble memory, magnetic drum, memory stick, Mylar® tape, smartdisk, thin film memory, zip drive, and so forth.

[0020] Referring again to FIG. 1, the system also includes an image processing circuit **140** configured to process the radiographic image **130** to identify enamel, dentine, pulp and caries layers of the tooth **110** and to detect caries on the tooth **110** based upon at least one texture parameter of the enamel, dentine, pulp and caries layers of the tooth **110** and the reference parameters. In the illustrated embodiment, the system **100** includes an X-ray generator **150** for illuminating the tooth **110** and an image capture device **160** configured to capture the radiographic image **130** of the tooth. Image capture may be performed by using any suitable illumination device and other imaging optics arrangement with possible configurations ranging from a single lens component to a multi-element lens. Examples of image capture device **160** include, but are not limited to, dental radio visual graphy equipment(RVG), intraoral dental x-ray unit and dental orthopantomography x-ray system

[0021] In operation, the X-ray generator **150** directs incident light at a suitable wavelength and energy level (e.g., X-rays) towards the tooth **110** to generate the radiographic image **130** which is acquired by the image capture device **160**. In certain embodiments, the image capture device **160** includes a monochrome camera or a color camera, or a conventional film. It should be noted that the radiographic images **130** of the tooth **110** may be pre-generated and stored in the memory circuit **120**. Further, such images **130** may be accessed by the image processing circuit **140** to detect the caries on the tooth **110**. In this embodiment, the system **100** also includes a display **170** for displaying the processed image with the detected caries on the tooth **110**. Where conventional film is used, the resulting images may be digitized for analysis in accordance with the teachings provided in this disclosure.

[0022] The image processing circuit **140** is configured to cluster image pixels of the radiographic image **130** to identify the enamel, dentine, pulp and caries layers of the tooth **110**. In certain embodiments, the radiographic image **130** is high-pass filtered to enhance edge details of the image **130**. In one example embodiment, the image processing circuit **140** includes a second order Butterworth high-pass filter to filter the radiographic image **130**. In this embodiment, a radius of filter cut-off frequency of the Butterworth high-pass filter is about 0.01.

[0023] In this example embodiment, the image processing circuit **140** employs C-means clustering for clustering the image pixels. However, other clustering techniques such as K-means clustering and fuzzy C-means clustering may be employed for clustering the image pixels.

[0024] Further, the image processing circuit **140** is configured to estimate at least one texture parameter for the enamel, dentine, pulp and caries layers using co-occurrence matrices. In this embodiment, the image processing circuit **140** utilizes gray level co-occurrence matrices (GLCM) to extract second order statistics from the radiographic image **130** for texture classification and estimation of texture parameters. As used herein, the term “gray level co-occurrence matrix” of an image is defined as a matrix of frequencies at which two pixels, separated by a certain vector, occur in the image.

[0025] In an embodiment, the distribution of the GLCM matrix depends on the angular and spatial relationship between pixels. Once the GLCM has been obtained, it can be used to compute texture parameters like entropy, angular second moment, contrast, inverse different moment, cluster tendency and cluster shade.

[0026] In an embodiment, the texture parameters obtained from the GLCM are utilized to classify and differentiate the caries from other tooth layers. In this example embodiment, the texture parameters are estimated separately for each of the enamel, dentine, pulp and caries layers. The image processing circuit **140** is configured to estimate a sum of square distance based upon the at least one texture parameter for each of the identified enamel, dentine, pulp and caries layers and the reference parameters. The caries on the tooth are subsequently differentiated from the other layers of the tooth based upon the estimated sum of square distance. The clustering of the image pixels and estimation of texture parameters from the radiographic image **130** will be described below with reference to FIGS. 2-5. Also, while reference is made to reference parameters of an image, it should be borne in mind that such reference parameters may, in practice, be based upon a group of images or image data that provide a reliable indication of the presence of caries.

[0027] FIG. 2 illustrates an example flow diagram **200** of an embodiment of a method for detecting caries on a tooth using the system **100** of FIG. 1. At block **210**, a radiographic image of the tooth is accessed. Further, the edge details of the radiographic image are enhanced by high-pass filtering the image (block **220**). The high-pass filtering can reduce random and structured noise in the image data and can enhance the quality of the image. In this embodiment, frequency domain filters are employed to transfer the accessed image into frequency domain and to separate the various tooth layers like enamel, dentine and pulp layers using edge details of the processed image. In one embodiment, a Butterworth high-pass filter is employed to enhance the edge details of the image. Examples of other filters include, but are not limited to, Chebyshev filter, Gaussian filter and elliptic filter.

[0028] In an example embodiment, the high pass filtered image transformed in a frequency domain may be represented by the following equation:

$$G(u,v)=H(u,v),F(u,v) \qquad (1)$$

[0029] Where:

F(u,v) is the Fourier transform of the input;
H(u,v) is filter transfer function; and
G(u,v) is the filtered image.

[0033] The transfer function of a Butterworth high pass filter of order ‘n’ with cut off frequency locus at a distance D_0 from the origin is represented by the following equation:

H □ (u , v) = 1 1 + [D 0 D □ (u , v)] 2 □ n (2)

[0034] Where: D_0 is the specified nonnegative quantity; and

[0035] D(u, v) is the distance from point (u, v) to the origin of the frequency plane; that is represented by the following equation:

$$D(u,v)=(u^{2}+v^{2})^{1/2} \qquad (3)$$

[0036] The filtered image using the filter described above yields a sharpened edge-enhanced image that is further processed for identifying the various layers of the tooth.

[0037] Once the edge-enhanced image is generated, the image pixels having similar pixel intensities are labeled with a gray level or a color and the labeled pixels are assigned to the enamel, dentine, pulp and caries layers based upon pre-determined thresholds for each of the enamel, dentine, pulp and caries layers. In the illustrated embodiment, the tooth image is scanned and the pixels are grouped into components based on pixel connectivity wherein all pixels in a connected component have similar pixel intensity values.

[0038] In an embodiment, after the scan is completed, the equivalent label pairs are sorted into equivalent classes and a unique label is assigned to each layer. In certain embodiments, a second scan of the image may be performed, during which each label is replaced by the label assigned to its equivalent layers. Further, the labeled pixels in the image are grouped into enamel, dentine and pulp layers based upon pre-determined thresholds.

[0039] At block **230**, image pixels of the edge-enhanced image are clustered to identify the enamel, dentine, pulp and caries layers (block **240**). A plurality of clustering techniques may be employed for clustering of the image pixels. Examples of such techniques include, but are not limited to, C-means clustering, K-means clustering and fuzzy C-means clustering. In the illustrated embodiment, C-means clustering is utilized for clustering which minimizes the total of the distances between the prototypes and the objects by construction of a target function.

[0040] The technique includes an initial partition matrix (U) that is used to estimate input values for the number of classes, iteration tolerance and the centers of clusters (classes). Subsequently, the membership values that each data point has in the cluster are recalculated using the center of clusters. Such values are compared with assumed values and this process is continued until the changes from cycle to cycle are within the prescribed tolerance level.

[0041] In this embodiment, the sum of squared errors approach using Euclidean norm is applied to characterize the distance within a class. The objective function algorithm is denoted as J(U,v) where U is the partition matrix and the parameter, v is a vector of cluster centers. The objective function is represented by the following relationship:

J □ (U , v) = ∑ k = 1 n □ ∑ i = 1 c □ x ik □ (d ik) 2 (4)

Where: d_{ik} is a Euclidean distance measure (in m-dimensional feature space, R^m) between the k^{th} data sample x_k and i^{th} cluster center v_i; and

d ik = d □ (x k - v i) = □ x k - v i □ = [∑ j = 1 m □ (x kj - v ij) 2] 1 2 (5)

[0043] Initially, the number of classes (c) and the number of objects (A), and a weighting factor m is selected where $1<m<\infty$. Further, the center vectors are estimated using the following relationship:

v ij = ∑ k = 1 n □ x ik □ x kj ∑ k = 1 n □ x ik (6)

[0044] Further, the $U^{(r)}$ matrix is updated by calculating the updated characteristic functions (for all i, k) using the following equation:

x ik r + 1 = { 1 d ik r = min □ { d jk r } □ □ □ for □ □ all □ □ □ j ∈ c 0 otherwise } □ □ If □ □ □ U (r + 1) - U r □ <= ε □ □ (tolerance □ □ level) □ □ then □ □ the □ □ □ process □ □ is □ □ completed , otherwise □ □ the □ □ value (7)

of r is incremented (r=r+1) and the process is repeated to achieve the desired tolerance level.

[0045] At block **250**, a plurality of texture parameters are determined for each of the identified dentine, enamel, pulp and caries layers. The texture parameters facilitate accurate image segmentation by quantifying the homogeneity and consistency of tissues across the radiographic image. In this example embodiment, co-occurrence matrices are used in the textural analysis of the image. In the illustrated embodiment, texture parameters such as entropy, angular second moment, contrast, inverse different moment, cluster tendency and cluster shade are computed from gray level co-occurrence matrices (GLCM) of the identified dentine, enamel, pulp and caries layers.

[0046] In certain embodiments, different colors are assigned to identified layers of the tooth to permit visualization of the layers. In particular, colors are assigned to monochrome images based on various properties of their gray level content of tooth layers. In this example embodiment, a plurality of planes may be disposed parallel to a co-ordinate plane of the image wherein each plane slices the image to identify different layers based upon an area of intersection. Subsequently, different colors are assigned to each layer. This pseudo coloring of the various layers facilitates identification of any discontinuity in the tooth pattern by increasing the distance in color space between successive gray levels.

[0047] At block **260**, the plurality of texture parameters are compared with reference parameters to detect the caries on the tooth. In one example embodiment, the plurality of texture parameters for each of the enamel, dentine, pulp and caries layers are compared with corresponding parameters of respective layers of a reference image. The parameters for the layers of the reference image may be separately measured and stored. In this example embodiment, a sum of square distance is estimated based upon the plurality of texture parameters and the reference parameters and the caries is detected based upon the estimated sum of square distance. In certain embodiments, a depth of the caries is determined by measuring a number of pixels in the caries layer.

[0048] FIG. 3 illustrates example images **300** generated by image processing of a radiographic image of a tooth using the system **100** of FIG. 1. In this embodiment, a single tooth from a dental X-ray image is isolated and is digitized to an average size of about 128×64 pixels. Further, radiological difference between the enamel, dentine, pulp and caries layers represented by reference numerals **310**, **320**, **330** and **340** is assessed using contrast variation of the various layers. This input X-ray image of the tooth is then preprocessed to enhance the edges to make the enamel **310**, dentine **320**, pulp **330** and caries **340** layers distrainable. Further, the pixels of the resultant image are labeled and the tooth layers are classified into enamel **310**, dentine **320**, pulp **330** and caries **340** layers using C-means clustering.

[0049] As described before, the labeled image pixels are assigned to different layers based upon pre-determined thresholds for each of the layers. In certain embodiments, the segmented layers **310**, **320**, **330** and **340** may be assigned different colors to facilitate visualization of the individual layers **310**, **320**, **330** and **340**.

[0050] Further, texture parameters are extracted from the co-occurrence matrices of the segmented layers **310**, **320**, **330** and **340** of the tooth image can be obtained through C-means clustering. Example values of texture parameters for a caries affected tooth are shown in table **400** of FIG. 4. As illustrated, texture parameters such as the entropy **410**, angular second moment (ASM) **420**, contrast **430**, inverse different moment (IDM) **440**, cluster tendency (CT**1**) **450** and cluster shade (CS**1**) **460** are estimated for each of the enamel, dentine, pulp and caries layers **310**, **320**, **330** and **340**. In one embodiment, these parameters correspond to a reference image of a tooth. Each of these parameters may be compared to corresponding parameters of respective layers of a test image to detect caries on the tooth.

[0051] In another embodiment, the texture features **400** of the image are compared with reference parameters to estimate the sum of squared distance. FIG. 5 shows example values for estimated sum of square distance obtained by comparing texture parameters **510** for an image with reference parameters **520** of a reference image. As illustrated, the sum of square distance is estimated by comparing texture parameters **530** and **540** of layers such as enamel and dentine layers with reference parameters **550** and **560** of corresponding layers of the reference image. Further, the sum of square distance is also estimated by comparing texture parameters **530** of layer such as the enamel layer with reference parameters **570** of a different layer such as the caries layer.

[0052] In an example embodiment, the sum of square distance estimated by comparing texture parameters with reference parameters of corresponding layers of the reference image results in a minimum sum of square distance value. In this example embodiment, the texture parameters for the caries layer of the image compared with the reference parameters of the caries layer of the reference image results in the minimum value of the sum of square distance, as represented by reference numeral **580**. This value of the sum of square distance **580** can facilitate detection of the carious lesion in the tooth.

[0053] The example methods and systems described above enable detection of caries on the tooth. The methods and systems discussed herein utilize an efficient, reliable, and cost-effective technique for performing diagnostic segmentation and classification to identify dental caries and to assess the extent of the caries lesion in the tooth. Such automated diagnostics aid a dentist in the assessment, treatment planning and evaluation of oral diseases such as dental caries. The technique provides complete information about the tooth including estimates of caries intrusion, even in root canals with extreme apical curvatures thereby increasing the diagnostic ease of the dental surgeon.

[0054] FIG. 6 is a block diagram illustrating an example computing device **600** that is arranged for detecting caries on a tooth in accordance with the present disclosure. In a very basic configuration **602**, computing device **600** typically includes one or more processors **604** and a system memory **606**. A memory bus **608** may be used for communicating between processor **604** and system memory **606**.

[0055] Depending on the desired configuration, processor **604** may be of any type including but not limited to a microprocessor (μP), a microcontroller (μC), a digital signal processor (DSP), or any combination thereof. Processor **604** may include one more levels of caching, such as a level one cache **610** and a level two cache **612**, a processor core **614**, and registers **616**. An example processor core **614** may include an arithmetic logic unit (ALU), a floating point unit (FPU), a digital signal processing core (DSP Core), or any combination thereof. An example memory controller **618** may also be used with processor **604**, or in some implementations memory controller **618** may be an internal part of processor **604**.

[0056] Depending on the desired configuration, system memory **606** may be of any type including but not limited to volatile memory (such as RAM), non-volatile memory (such as ROM, flash memory, etc.) or any combination thereof. System memory **606** may include an operating system **620**, one or more applications **622**, and program data **624**. Application **622** may include an image processing algorithm **626** that is arranged to perform the functions as described herein including those described with respect to process **200** of FIG. 2. Program data **624** may include reference texture parameters **628** that may be useful for detecting the caries as is described herein. In some embodiments, application **622** may be arranged to operate with program data **624** on operating system **620** such that determination of the quotient values based upon the intermediate remainder value may be performed. This described basic configuration **602** is illustrated in FIG. 6 by those components within the inner dashed line.

[0057] Computing device **600** may have additional features or functionality, and additional interfaces to facilitate communications between basic configuration **602** and any required devices and interfaces. For example, a bus/interface controller **630** may be used to facilitate communications between basic configuration **602** and one or more data storage devices **632** via a storage interface bus **634**. Data storage devices **632** may be removable storage devices **636**, non-removable storage devices **638**, or a combination thereof.

[0058] Examples of removable storage and non-removable storage devices include magnetic disk devices such as flexible disk drives and hard-disk drives (HDD), optical disk drives such as compact disk (CD) drives or digital versatile disk (DVD) drives, solid state drives (SSD), and tape drives to name a few. Example computer storage media may include volatile and nonvolatile, removable and non-removable media implemented in any method or technology for storage of information, such as computer readable instructions, data structures, program modules, or other data.

[0059] System memory **606**, removable storage devices **636** and non-removable storage devices **638** are examples of computer storage media. Computer storage media includes, but is not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which may be used to store the desired information and which may be accessed by computing device **600**. Any such computer storage media may be part of computing device **600**.

[0060] Computing device **600** may also include an interface bus **640** for facilitating communication from various interface devices (e.g., output devices **642**, peripheral interfaces **644**, and communication devices **646**) to basic configuration **602** via bus/interface controller **630**. Example output devices **642** include a graphics processing unit **648** and an audio processing unit **650**, which may be configured to communicate to various external devices such as a display or speakers via one or more A/V ports **652**. Example peripheral interfaces **644** include a serial interface controller **654** or a parallel interface controller **656**, which may be configured to communicate with external devices such as input devices (e.g., keyboard, mouse, pen, voice input device, touch input device, etc.) or other peripheral devices (e.g., printer, scanner, etc.) via one or more I/O ports **658**. An example communication device **646** includes a network controller **660**, which may be arranged to facilitate communications with one or more other computing devices **662** over a network communication link via one or more communication ports **664**.

[0061] The network communication link may be one example of a communication media. Communication media may typically be embodied by computer readable instructions, data structures, program modules, or other data in a modulated data signal, such as a carrier wave or other transport mechanism, and may include any information delivery media. A “modulated data signal” may be a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media may include wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, radio frequency (RF), microwave, infrared (IR) and other wireless media. The term computer readable media as used herein may include both storage media and communication media.

[0062] Computing device **600** may be implemented as a portion of a small-form factor portable (or mobile) electronic device such as a cell phone, a personal data assistant (PDA), a personal media player device, a wireless web-watch device, a personal headset device, an application specific device, or a hybrid device that include any of the above functions. Computing device **600** may also be implemented as a personal computer including both laptop computer and non-laptop computer configurations.

[0063] The present disclosure is not to be limited in terms of the particular embodiments described in this application, which are intended as illustrations of various aspects. Many modifications and variations can be made without departing from its spirit and scope, as will be apparent to those skilled in the art. Functionally equivalent methods and apparatuses within the scope of the disclosure, in addition to those enumerated herein, will be apparent to those skilled in the art from the foregoing descriptions. Such modifications and variations are intended to fall within the scope of the appended claims.

[0064] The present disclosure is to be limited only by the terms of the appended claims, along with the full scope of equivalents to which such claims are entitled. It is to be understood that this disclosure is not limited to particular methods, reagents, compounds compositions or biological systems, which can, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

[0065] With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity.

[0066] It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as “open” terms (e.g., the term “including” should be interpreted as “including but not limited to,” the term “having” should be interpreted as “having at least,” the term “includes” should be interpreted as “includes but is not limited to,” etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present.

[0067] For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases “at least one” and “one or more” to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles “a” or “an” limits any particular claim containing such introduced claim recitation to embodiments containing only one such recitation, even when the same claim includes the introductory phrases “one or more” or “at least one” and indefinite articles such as “a” or “an” (e.g., “a” and/or “an” should be interpreted to mean “at least one” or “one or more”); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should be interpreted to mean at least the recited number (e.g., the bare recitation of “two recitations,” without other modifiers, means at least two recitations, or two or more recitations).

[0068] Furthermore, in those instances where a convention analogous to “at least one of A, B, and C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “a system having at least one of A, B, and C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to “at least one of A, B, or C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “a system having at least one of A, B, or C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.).

[0069] It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms. For example, the phrase “A or B” will be understood to include the possibilities of “A” or “B” or “A and B.”

[0070] In addition, where features or aspects of the disclosure are described in terms of Markush groups, those skilled in the art will recognize that the disclosure is also thereby described in terms of any individual member or subgroup of members of the Markush group.

[0071] As will be understood by one skilled in the art, for any and all purposes, such as in terms of providing a written description, all ranges disclosed herein also encompass any and all possible subranges and combinations of subranges thereof. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, tenths, etc. As a non-limiting example, each range discussed herein can be readily broken down into a lower third, middle third and upper third, etc. As will also be understood by one skilled in the art all language such as “up to,” “at least,” “greater than,” “less than,” and the like include the number recited and refer to ranges which can be subsequently broken down into subranges as discussed above. Finally, as will be understood by one skilled in the art, a range includes each individual member. Thus, for example, a group having 1-3 cells refers to groups having 1, 2, or 3 cells. Similarly, a group having 1-5 cells refers to groups having 1, 2, 3, 4, or 5 cells, and so forth.

[0072] While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

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* Cited by examiner, † Cited by third party

Cited By (3)

Publication number	Priority date	Publication date	Assignee	Title
WO2016084066A1	2014-11-27	2016-06-02	A. B. Imaging Solutions Ltd	Intraoral 3d scanner
WO2016123465A1 *	2015-01-30	2016-08-04	Dentsply International, Inc.	System and method for adding surface detail to digital crown models created using statistical techniques
US9814549B2	2015-09-14	2017-11-14	DENTSPLY SIRONA,	Method for creating flexible arch model of teeth for use in restorative dentistry

Inc.
Family To Family Citations

* Cited by examiner, † Cited by third party, ‡ Family to family citation

Similar Documents

Publication	Publication Date	Title
Byng et al.	1996	Automated analysis of mammographic densities
Yaffe	2008	Mammographic density. Measurement of mammographic density
Gravel et al.	2004	A method for modeling noise in medical images
Cortes et al.	2003	An in vitro comparison of a combined FOTI/visual examination of occlusal caries with other caries diagnostic methods and the effect of stain on their diagnostic performance
Miniati et al.	1995	Radiologic evaluation of emphysema in patients with chronic obstructive pulmonary disease. Chest radiography versus high resolution computed tomography.
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Wenzel et al.	1990	Depth of occlusal caries assessed clinically, by conventional film radiographs, and by digitized, processed radiographs
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Priority And Related Applications

Priority Applications (2)

Application	Priority date	Filing date	Title
IN2760/CHE/2009		2009-11-11	
IN2760CH2009		2009-11-11	

Applications Claiming Priority (1)

Application	Filing date	Title
PCT/IB2010/054359	2010-09-28	Dental caries detector

Legal Events

Date	Code	Title	Description
2009-12-30	AS	Assignment	**Owner name**: THIAGARAJAR COLLEGE OF ENGINEERING, INDIA **Free format text**: ASSIGNMENT OF ASSIGNORS INTEREST;ASSIGNORS:BANUMATHI, A.;RAJU, S.;ABHAIKUMAR, V.;REEL/FRAME:023719/0761 **Effective date**: 20091215

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GEOGRAPHICAL INDICATIONS

Docket NO : 12449

005076

Date/Time :
03/06/2013
Agent Number:

To
Dr. R. VASUDEVAN
DEN ECA, PROF. DEPT. OF CHEMISTRY, THIAGARAJAR COLLEGE OF ENGINEERING, TIRUPARANKUNDRAM, MADURAI - 625 015.

Sr. No.	CBR Number	Reference Number /Application Type	Application Number	Title/Remarks	Amount Paid	Amount Computed
1	7691	Renewal Fee - 12th Year	198254	---	12000	12000
Total Amount					12000	12000

Received a sum of Rs. 12000 (Rupees Twelve Thousand only) as under

Payment Mode	Bank Name	Cheque/Draft Number	Cheque/Draft Date	Amount in Rs
Draft	ICICI Bank	006461	28/05/2013	12000

Note: This is electronically generated receipt hence no signature required.

Detail

APPLICATION NUMBER	3210/CHE/2015
APPLICANT NAME	1.N. SUBRAMANIAN 2. B.THIRUCHITRAMBALAM
DATE OF FILING	26/06/2015 11:18:37
PRIORITY DATE	NA
TITLE OF INVENTION	A REMOTE CONTROLLED MULTI CROP SEED PLANTING MACHINE
PUBLICATION DATE (U/S 11A)	10/07/2015

Application Status

Request For Examination Date	26/06/2015 11:18:37
Status	Application Awaiting Examination

Detail

APPLICATION NUMBER	3577/CHE/2014
APPLICANT NAME	N. SUBRAMANIAN
DATE OF FILING	22/07/2014 11:42:25
PRIORITY DATE	NA
TITLE OF INVENTION	VISUAL CONTROL APPROACH FOR DETECTION OF FUEL LEVEL IN GAS CYLINDER INCORPORATED WITH GSM TECHNOLOGY
PUBLICATION DATE (U/S 11A)	12/09/2014

Application Status

Request For Examination Date	22/07/2014 11:42:25
Status	Application Awaiting Examination

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GOVERNMENT OF INDIA

Controller General of Patents,Designs and Trademarks
Department of Industrial Policy and Promotion
Ministry of Commerce and Industry

Application Details	
APPLICATION NUMBER	201641022395
APPLICATION TYPE	ORDINARY APPLICATION
DATE OF FILING	30/06/2016
APPLICANT NAME	**THIAGARAJAR COLLEGE OF ENGINEERING**
TITLE OF INVENTION	SEAT RING CLEARANCE PROVIDER MAINTENANCE TOOL FOR GATE VALVE AND METHOD OF MAINTENANCE THEREOF
FIELD OF INVENTION	MECHANICAL ENGINEERING
E-MAIL (As Per Record)	intellpat@gmail.com
ADDITIONAL-EMAIL (As Per Record)	
E-MAIL (UPDATED Online)	
PRIORITY DATE	NA
REQUEST FOR EXAMINATION DATE	--
PUBLICATION DATE (U/S 11A)	06/04/2018

Application Status	
APPLICATION STATUS	Application Published

US 20120304562A1

(19) **United States**
(12) **Patent Application Publication** (10) **Pub. No.: US 2012/0304562 A1**
Ibrahim et al. (43) **Pub. Date: Dec. 6, 2012**

(54) **ARCHITECTONIC SPACER BUILDING SYSTEM**

(75) Inventors: **Rahinah Ibrahim**, Serdang (MY); **Siva Jaganathan**, Serdang (MY)

(73) Assignee: **Universiti Putra Malaysia**, Selangor (MY)

(21) Appl. No.: **13/436,144**

(22) Filed: **Mar. 30, 2012**

Related U.S. Application Data

(63) Continuation-in-part of application No. PCT/MY2009/000203, filed on Dec. 4, 2009.

(30) **Foreign Application Priority Data**

Oct. 1, 2009 (MY) .... PI 20097019

Publication Classification

(51) **Int. Cl.**
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E04B 1/98 (2006.01)

(52) **U.S. Cl.** **52/220.1**; 52/650.2

(57) **ABSTRACT**

The architectonic spacer building system is a simplified prefabrication assembly using industrialised building system concept. The architectonic spacer building system for skeleton construction includes a spacer (**2**, **4**, **6**, **8**, **10**) having a predetermined shape for use in constructing modular form of building components, including a modular floor joist assembly (**18**), corner and crisscross junctions assembly (**17**, **19**). The spacer acts as an anchored dowel connector (**2**, **10**), composite key roof connector (**22**, **24**, **26**) and/or a bracing (**2**, **4**, **6**, **8**) of adjoining wall panel (**12**).