An ECG Document Imaging System towards a Cardiology EMR

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Abstract—**We present a document imaging system which scans various types of ECG sheets and stores the scanned sheets as JPEG image files to be retrieved by cardiologists. In our implementation, we use two simple machine learning techniques: one for classifying the ECG form and the other for recognizing a required set of attribute values depending on the scanned form. In order to classify an ECG form, as a training step, we built an average histogram for each ECG form using a pre-classified set of training data. A newly scanned image is assigned to the form that is in nearest distance on its histogram. To recognize a set of important attribute values, we used a multi-layered neural network and back propagation algorithm normally used in OCR. ECG sheets differ in layout and thus attributes. We analyzed each form of ECG sheets and constructed an XML file representing a set of attributes whose values are to be recognized later on. We have tested our system with a number of sheets printed from six different ECG devices including 12-lead ECG and Treadmill. When a 12-lead ECG sheet is scanned by a high-speed scanner, for instance, its image is classified and saved into the corresponding class, and a major set of attribute values is recognized and saved in the system's database; in our case, we use the attributes such as the patient's number, test date and time, Rate, PR, QRSD, QT, QTc, Axis (P, QRS, T).**

Keywords—**ECG, Neural network, OCR, Nearest neighbor**

I. Introduction

Document imaging (also known as digital imaging) is a process where a paper-based document is converted from its human-readable format into a computer-readable format. Hospitals are adopting the electronic medical system (EMR) which stores all the information about a patient's treatment, diagnosis, and prescription in an electronic document. Additionally, many imaging systems of paper-chart documents are being developed in various forms and functions [1].

However, large medical institutions such as university hospitals use numerous medical equipments, each of which prints out paper documents in different formats. Thus, the necessity for proper management of these paper documents is evident [2]. Since the readings and annotations by physicians are added to these paper documents with printed examination results, the availability for a fast retrieval is often needed. Especially, for data mining which enables the detection of important medical data, converting the paper document into an electric format through scanning is critical.

In the case of electrocardiogram (ECG) measurement, which presents the cardiac electric activity in a diagram, many different devices are used including the widely adopted 12-lead ECG or Treadmill. These individual types print the results in different formats. Therefore, these ECG documents strongly require an imaging system to convert them into electronic formats as well. An ECG document imaging system should recognize not only the printed image in the document but also the patient and ECG data in great accuracy. Furthermore, the patient-based classification of the documents needs to be accompanied by format-based classification.

Our study presents an application software which: scans ECG sheets into image files; classifies the ECG form by the image; recognizes the text and numeric data contained in the image; and saves the image attribute values in the database for management. Nearest neighbor algorithm with histogram [3] was used to classify the ECG form by the images, and text recognition was processed by multi-layered neural network algorithm.

II. Electrogardiogram

Electrocardiogram is an electric signal representing the cardiac electric activity which is measurable on body surface. An ECG document presents this electric signal in wave patterns and its temporal variation in diagram and numeric data.

ECG documents can be classified into several types of documents, which themselves have deviations in forms. So these documents need to be well classified. After classification, numeric data of the document are recognized. Yet the numeric data of each document have different position and type thereby requiring a definition for each document type.

Figure 1 is a part of a 12-lead ECG document sample image. In this image, Rate, PR, QRSD, QT, QTc, P, QRS, T values are the numeric data to be recognized. The squared-region is the region to be recognized in this image.

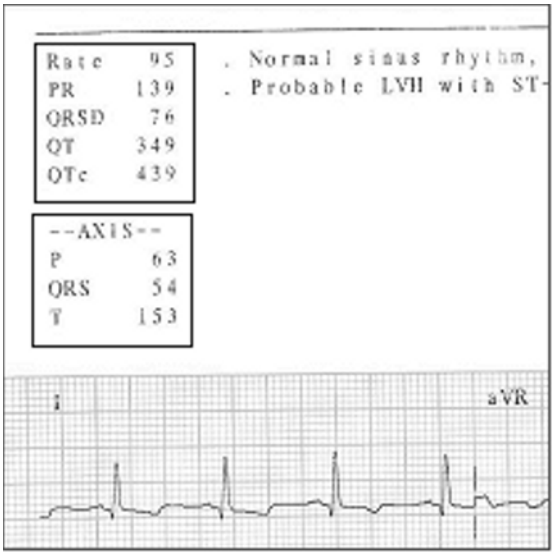

Fig. 1 A 12-lead ECG document sample

III. Data Extraction

In order to recognize ECG document data, document classification is required in advance. Therefore, document classification by characteristic extraction is followed by image calibration for more accurate recognition. Finally, recognition is processed using the numeric data position and format data of the corresponding document type.

A. Data Structure for Document Type Information

Basic data is necessary to classify or recognize the document type information. This is saved and administered as an XML file in the format shown in Table 1.

Table 1 XML for document type information

```
<Document>
 <Form Type="1" Desc="A">
  <Edge>
   <Rect>100,140,1000,120</Rect>
  </Edge>
  <Regions>
   <Region>
    <Pos>90, 1, 220, 100</Pos>
    <Annotation>Rate</Annotation>
    <Expr>Rate ##</Expr>
    <HistXNoise>0</HistXNoise>
    <HistYNoise>2</HistYNoise>
    <BlockGap>35</BlockGap>
   </Region>
  </Regions>
</Document>
```

The XML file contains information such as document type, boundary line detection region, and recognition region. Under the recognition region, detailed items contain the structural information of the paragraph in the region which contributes to reduce recognition error.

B. Image Classification

For image classification, nearest-neighbor algorithm is the most efficient. The nearest-neighbor algorithm extracts a set of attributes for each document type and classifies with the closest (nearest) characteristic value.

For example, consider three document types A, B, and C where A has a red component while B and C both do not, but each (B and C) exhibits difference in text position. The characters of A, B, and C are analyzed, and the region of character is found. When there is an input of a new image, the region of character is subjected to characteristic value measurement such as color component or degree of similarity. Then the image is classified with the document sharing closest characteristic values.

C. Image Calibration

Once the document is classified, image calibration is necessary. This is due to the scanning process, which can tilt the image. It leads to lower accuracy of text region extraction. The tilted image is calibrated by measuring the base line in each document type.

To use a base line for image calibration, boundary line detection algorithm is applied first. Then the detected base line region is expanded by the expansion filter in order to prevent the non-detection of the base line which occurs when then the base line is thin or cut by noise. Finally, the regional coordinates of the detected base line is used to find the displacement from which the tilting can be computed.

Figure 2 is after applying the boundary line detection filter on the image in Figure 1, and Figure 3 shows the application of the expansion filter on Figure 2. It is apparent that the base line is clearer compared to the previous step. Figure 4 shows the image after calibration using the detected base line.

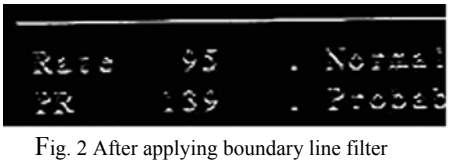

Fig. 2 After applying boundary line filter

Fig. 3 After applying expansion filter

Fig. 4 After calibration

D. Region Extraction and Recognition

Recognition process starts with dividing individual text regions in the user-defined region followed by recognition using the neural network. Region division plays a critical role in this recognition process. A number of variables affects region division. One example is noise produced in the image scanning or handling process.

In order to overcome these problems, our study divided regions in several steps as:

1) Y-axis standard line division; 2) pixel tracking division; 3) size analysis of divided region; 4) re-division of abnormal image.

The first step divides a line by analyzing a histogram with the Y-axis as standard. The second step scans each divided line image from the Y-axis center to the right end. For pixels with colors lower than the critical value, difference between pixel values of the eight-neighboring-pixels determines if the pixel is in the same text region, leading to region detection. Among the regions detected through pixel tracking, those with inappropriate image proportions are considered to contain more than one letter. These regions are subjected to re-division.

IV. ECG MANAGEMENT

Our study developed an image management system using ECG image recognition module. When the user starts scanning an ECG document, the recognition module scans the document, classifies and recognizes it, and finally presents it categorized based on document-type and patient. Thus the task of the user is minimized to examination after the entire process.

A. System Configuration

Figure 5 shows the overall system architecture of our ECG imaging system.

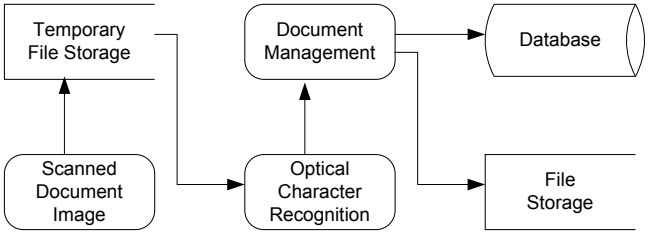

Fig. 5 System architecture

ECG documents are scanned and saved as image files in local temporary saving space. The recognition module processes document classification, region detection, and recognition and saves the resulting data.

After the entire process, the user modifies the data. Finally, the recognized data and image files are saved in the server database and file saving space, respectively. The saved data are available for search under various conditions.

B. Document Management

The constructed system is a document imaging system which has many necessary functions. The important functions are as the following:

1) image management based on document-type and patient; 2) view thumbnail by size; 3) addition of image annotation

Figure 6 is the window after scanning the image, which was used in the image recognition module part, through the application program. The scanned image is presented in thumbnail which can be enlarged into a larger image when selected. In the lower part, the attribute values recognized from the image are listed.

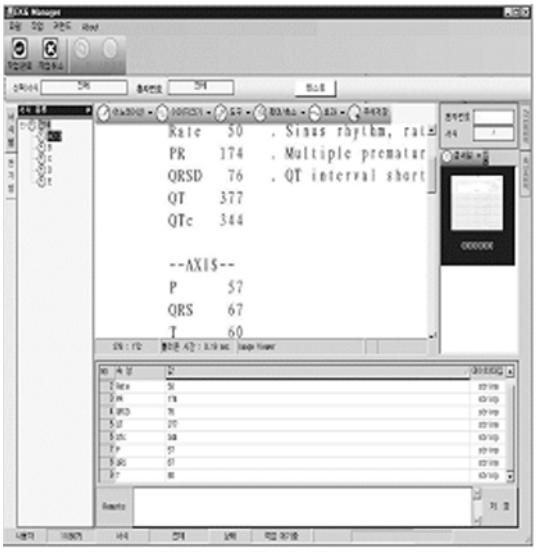

Fig. 6 Main application program

C. Attribute Retrieval

Attribute retrieval is a way to utilize the attribute values of ECG images. This attribute retrieval searches an image based on the attributes of the image. Figure 7 is a window under the attribute retrieval process which is searching for all images satisfying condition "Rate >= 50 AND QT >= 200" in document type "A."

Fig. 7 Attribute retrieval

V. Conclusion and Future Directions

Our study presented an image system which converts ECG documents into image files, classifies them, and recognizes the image attribute values. The developed system is capable of automatic classification, calibration, and recognition for six different ECG images. This significantly reduces the waste of time, space, and effort that were required for the management of ECG paper documents. Also the saved attribute values can be used for data mining.

As future directions, we plan to develop a function which can detect the possibility of cardiac disease onset by extracting and learning wave patterns in the ECG images [4] for an advanced cardiology EMR system.

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