Chest X-Ray Analysis for an Active Distributed E-Health System with Computer-Aided Diagnosis

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Abstract- **The quality of life of a country's citizens is much depended on its healthcare system. People have the right to know the status of their health. Healthcare providers need to know the medical histories of patients to offer better treatment. Therefore, demand for improvement in the access of healthcare information has been increased. This paper presents the design of an active distributed E-health system, which is scalable, and more advanced softwares can be easily added. Some works on chest X-ray analysis are presented to demonstrate the capabilities of the system as CAD tools for some chest diseases like congestive heart failure, lung collapse, etc. Experimental result obtained with an algorithm to detect early nodules for lung cancer and TP is very encouraging. Data mining and other artificial intelligent techniques may be used to make the system becoming more active and powerful expert system**

Keywords: − **E-health, Distributed system, Computer aided diagnosis, Artificial intelligence, Data mining**

I. INTRODUCTION

Healthcare information, including patients' records such as examination results, medication history and diagnoses, etc., is a rich source of medical knowledge, but has not been used efficiently for medical treatment as well as financial management. They are often not nationally accessible due to the vast majority of healthcare information is in paper-based storages.

If patients are permitted to access their medical records, they can monitor their health statuses to cooperate in treatment, and to contribute in early detection of any abuse of health care systems. When healthcare providers can access comprehensive medical records, they can offer their patients better treatment.

In Australia, Federal, State and Territory governments have committed to working together to introduce E-health communications with the aim: "Ultimately, Australians will have access to a secure electronic health record" [7].

This paper introduces our humble contribution towards an active distributed E-Health System.

In some healthcare systems, people are automatically scheduled for regular general check-up sessions as well as advanced X-rays, CT (Computed Tomograph) or MRI (Magnetic Resonance Imaging) pre-scans. These images are numerous, and need a lot of human time to diagnose. However, softwares may be developed to analyse the images and sort patients into different categories depending on their severity levels, so that medical specialists can schedule their examination lists.

Advances in data mining techniques make medical knowledge hidden in patients' data being discovered to be used in expert systems. However, in medical applications where a decision may have fatality effects, the obtained knowledge can only play a supportive role to give professionals the means to check and evaluate their judgements.

An artificial medical expert can also be useful and efficient to give quick proposals for first-aid advice or treatments in simple but common sicknesses like headache, cold, etc.

A number of advisory systems are available for medical and educational purposes: DXPlain, Gideon, Iliad, etc. [3]. These systems store a huge amount of medical information on various diseases, but none of them really focuses on nationwide access, and especially Computer-Aided Diagnosis (CAD) equipped with artificial intelligent technologies has not been appropriately given much attention.

The paper is organised as follows. Section II outlines our proposal for a national active, distributed E-health system. Section III presents some works on chest X-ray analysis for CAD tools, which are our main contribution in this paper. The paper ends with a brief conclusion.

II. E-HEALTH SYSTEM

The proposed E-health system has been designed with careful consideration on characteristics of a distributed system, especially those of security, scalability, concurrency, consistency and tolerance. The system also has capability of an expert system to introduce the activeness. The E-health system is organised into two layers (Fig. 1), one at the foreground for user interface based on the Web technology, the other at the background for data analysis and management using TCP client-server models. A health data system is used as the communication medium between the two layers.

A. E-health System Structure

The E-health system is composed of a central site –E-health Central, many provincial sites –E-Clinic, and some health Support service sites –E-health Support (Fig. 2).
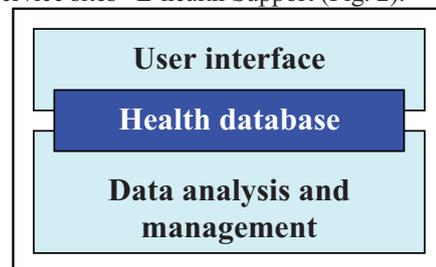

Fig. 1: The E-health system is organised into two layers: User interface, and Data analysis and management. They are linked together by the Health databases.
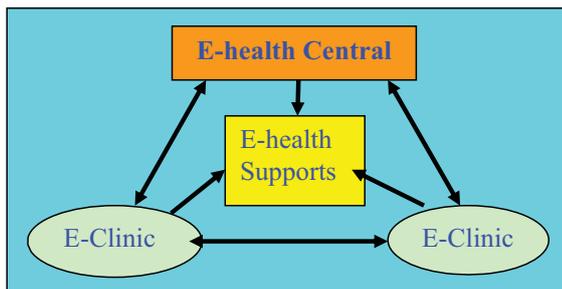
Fig. 2: The E-health system is composed of an E-health Central, many E-Clinics and some E-health Support services.

1) *E-health Central:* The E-health Central has two databases: One shows to which E-Clinic a citizen is registered; another holds medical records of all citizens, which is a nationwide backup of citizens' medical records in all E-Clinic databases. The Central also has a list of super-users who can access the site.

2) *E-Clinic:* An E-Clinic has two databases, one holding authorized users, another with medical records of the citizens registered to that clinic.

3) *E-health Support*: The E-health Supports are to offer general medical information like first aids, medicine usage, etc. Some special E-health Supports are dedicated to clinical procedures like treatment, examination, surgery, etc., which are nationwide standardised.

B. *User Interface*

The Web technology is used for users' interface with the E-health system.

1) *User classification:* Users for the E-health system are classified into some (e.g. five) categories like visitor, patient, clinic staff, pharmacist, IT administrator, each being assigned with an access level, 1, 2, 3, 4 or 5, respectively, with 5 is the highest access level. A registered user can access the associated E-Clinic directly. A patient or a visitor who tries to access the E-health system via the E-health Central will be redirected to an associated E-Clinic or an E-health Support. Web browser cookies may also be used to redirect a user to an E-Clinic.

2) *Access privilege:* User accesses are careful assigned for security and privacy reasons. E-health system facilities are marked with different access levels. Patients can access their own medical records at an associated E-Clinic through a Web browser. However they can only have read or write accesses to some fields of the records like home addresses, telephone numbers, etc. When a patient visit a registered chemist, a pharmacist can login a local E-Clinic to access the patient's medical record to see doctors' prescriptions and supply medicine as required. By supplying a patient's ID to the E-health Central, pharmacists will also be redirected to the E-Clinic where the patient being registered. If it is time for a prescription repeat, the E-clinic will alert the patient in time using emails or phone. Chemists are also informed for stock preparation.

Clinic staff can access patients' records to supervise treating progress. They can also make requests to transfer a patient's record from one E-Clinic to another.

Super-users (e.g. IT administrators, software agents, etc.) have the access right to all E-health system facilities.

C. *Patients' Data Management*

Patients' medical records are accessed using Web browsers. The backup and the transfer of patients' records are performed by background operations using the TCP client-server technology. To perform records backup or transfer, an authorised user logins at the Web server of an E-Clinic, e.g. E-Clinic EC_I, and makes a request for backup the record of a patient, e.g., *Request = Backup (R_P)*, or a request for sending/obtaining the record R_P to/from another E-Clinic, e.g., *Request = Send (R_P, EC_J) / Request = Get (R_P, EC_J)*.

1) *Patients' records backup*: At every E-Clinic as well as at the Central, there is a set of TCP client (TC) and server (TS) programs. When a patient's record R_P is modified at E-Clinic EC_I, e.g., through the Web Server WS_I, an associated item, e.g. *Backup (R_P)*, is added to the updating list of the clinic. The TCP client at that clinic (i.e., TC_I) is regularly pulled out of a sleeping mode to check the list and send the modified records to the TCP server at the Central (TS_C). With this arrangement, there is a short interval during which the two copies of a patient's record are different. This approximately satisfies the consistency requirement of a distributed system.

2) *Patients' records transfer*: When the transfer of a patient's record between two E-Clinics is not urgent, it can be performed more efficiently by background operations. For example, when clinical staff members at E-Clinic EC_I want to get (or send) the medical record R_P from (to) E-Clinic EC_J, they first login at the Web server WS_I, and put a request, e.g. *Get (R_P, EC_J)* or *Send (R_P, EC_J)*, into the updating list at E-Clinic EC_I. When the TCP client TC_I is awaken again, it will make a connection to the TCP server at the E-Clinic EC_J (i.e. TS_J) to obtain or send the record R_P. If there is a request *Backup (R_P)* at EC_I or EC_J, this backup item must be completed before the request *Get (R_P, EC_J)* or *Send (R_P, EC_J)* being performed. When the transfer is completed, TC_I will inform TS_C the transfer so that TS_C can update the Central database.

Patients' Records Backup and Transfer Algorithm:
The TCP client at an E-Clinic, e.g. TC_I, will be regularly pulled out of a sleeping mode. When awaken, TC_I will perform the backup and transfer as follows.

Record backup: If there are backup requests, e.g. *Backup (R_P)*, TC_I makes a TCP connection to TS_C and sends all modified records. When completed, TC_I asks TS_C to close the connection.

Record transfer: If there are transfer requests, e.g. *Get (R_P, EC_J)* or *Send (R_P, EC_J)*, TC_I will perform the transfers as follows:

a) TC_I makes a TCP connection to TS_J;
b) TC_I sends requests for every *Get (R_P, EC_J)* to TS_J.

- TS_J checks whether there is a pendent backup request on the R_P record. If so, TS_J will inform TC_I and not send the record as requested; otherwise, it sends the record R_P to TC_I.

- Upon receiving every transferred record, TC_I informs TS_J that the transfer is successful, and TS_J can delete the record from its database.
c) TC_I informs TS_J that it does not want to receive any more record, and will continue with requests for record sending, if any.
d) TC_I sends all patients' records for every *Send (R_P, EC_J)* to TS_J.
    - TC_I sends record R_P to TS_J.
    - Upon receiving every record, TS_J informs TC_I that the transfer is successful, and TC_I can delete the record from its database.
e) TC_I informs TS_J that it has no more record to send. TS_J closes the connection.
f) TC_I makes a TCP connection to TS_C and inform the transfers so that TS_C can update its database of patients' registration.

D. E-Health Support Services

E-health Support services are offered from the Web servers of the E-health Supports. Some services are generally available to all users; the others are accessible only to medical staff. Popular support services are replicated at E-Clinics for fast services.

1) *Clinical procedures*: Clinic staff can refer clinical procedures like examination, diagnosis, surgery, etc. to prepare and perform clinical processes. These procedures are nationally standardised, hence clinic staff can feel at home while working at any clinic when requested, and all patients are treated with the same quality. Clinical processes can also be remotely supervised. Hence specialists are not necessary to be presented at the clinics where their colleagues are performing the processes.

Progress of a clinical procedure can also be recorded to E-Clinic databases using wireless devices like laptop, PDA, etc. This facility can avoid mistakes like those often occurring with hand-written records.

Clinical procedures can also used for clinical training. Some clinical procedures may be localised to suit the facilities at some special clinics. Clinical procedures that are often used at a clinic may be replicated at the local E-Clinic. This arrangement can lighten the Internet bottle neck problem at the E-health Supports.

2) *General medical information*: Useful medical information like first aids, medicine usage, etc. can be widely made available through E-health Support Web sites.

E. Other E-health Facilities

1) *Patients' Examination Appointments:* Regular patients' checks like annual chest scan, general health examination, etc. can be scheduled in background operations at every E-Clinic based on the availability of clinical facilities as well as patients' proposals. Once confirmed, appointments will be added to patients' records, and some facilities like emails, phone messages, etc. will be used to inform them.

2) *Home Treatment Supervision*: Home treatment examination data can be recorded to patients' computer or PDA using Sensor Web technology, and are then sent to E-Clinics to save in the patients' medical records. The facilities

are similar to that used at physical clinics during clinical procedure performance. The designed E-Clinic has been tested with simulated PDA. The work with wireless sensors is in progress.

III. CXR IMAGE ANALYSIS

For the overall view of a chest X-ray (CXR), the entire lung boundaries will be detected to isolate lungs from the background. Different techniques can be used to find lungs boundaries. Once lung objects have been isolated, the CXR is analysed to detected abnormalities like heart failure, lung collapse, TP or cancer nodules, etc.

A. Lung Isolation:

On an X-ray image, the gray levels of pixels, ranging from 0 (black) to 255 (white), depend on both the thickness of tissues and their atomic weights, and they are clustered in the middle range of gray levels, and those of air and bone pixels are in the two extremes, black and white, respectively. In the case of a CXR image, the two lungs are darker than the background, and are easy to recognise (Fig. 3a)

The Watershed segmentation [2] was originally used in topography to partition an area into regions. A Watershed segmentation process starts at some regional minima L_I, the lowest points in the area that water can flow into. The area is divided into some regions V_I (valleys) that are grown from the corresponding minima L_I by adding to V_I, iteratively, unlabelled higher points on their boundaries. The addition is repeated until no more point can be assigned to any region.

In the case of a CXR image, gray levels play the role as that of ground levels in topography. The Watershed segmentation can be used to isolate the two lungs and the dark background. However the existence of the bright region between the two lungs and the bright regions of ribs, shoulder bones, etc. make the original Watershed segmentation unable to be stopped accurately at the lung boundaries. We propose two modifications:

a) In addition to the minima L_I, we also find some maxima H_J, the highest points. The regions that originally consist of these maxima are called M_J (mountain). The mountain regions are grown, in concurrence with the growing of the valleys, by adding to M_J unlabelled lower points on their boundaries. The modified Watershed segmentation is carried on with the growing of all valleys V_I and mountains M_J. The segmentation is completed when there is no more point can be added to any region.

b) When the modified Watershed segmentation is complete. The boundaries between a lung and the mediastinum may be too far within the mediastinum. A drying process, starting from the maxima, will push the lung boundary back.

The Watershed-based segmentation to find lungs' boundaries of a CXR image is summarised and is illustrated as follows.

Lung Boundary Detection Algorithm:

a) Find the gray level histogram for the CXR.

b) Based on the histogram, choose six gray levels GL[i], i = 0, 1, …, 5, which are used to sort the pixels of the CXR into five regions Region [j], j = 0, …, 4, each with

a specific percentage of pixels P[j], e.g. 20%, 10%, 20%, 20% and 30%, with P[0] = 20% for Region [0], P[1] = 10% for Region [1], etc., so that

$$\forall pixels \in Region[j], \quad pixel.grayLevel \in [GL[j],GL[j+1]]$$

$$j = 0,...,4$$

Where GL [0] = 0 and GL [5] = 255, the minimal and the maximal gray levels respectively.

The lung cores (valleys) including pixels with gray levels less than GL [1] then should be in Region [0] (Fig. 3b). Dark pixels on the narrow strips along the left and the right sides of the CXR image (Fig. 3c) also belong to Region [0]. Brighter pixels (mountains) in a short vertical strip at the middle of the image belong to Region [3] or Region [4] (Fig. 3c).

To differentiate dark pixels of lung cores from dark pixels of the background, we divide the CXR into 4x4 rectangles R [i, j], i, j = 0, 1, 2 & 3.. The dark pixels lying in the four central rectangles, i.e. R [m, n], m, n = 1, 2, should belong to lung cores, and are labelled with +1. The dark pixels on the strips along the left and the right sides of CXR should belong to the background and are labelled with −1. The bright pixels in the vertical strip mentioned above should belong to the background and are labelled with −2.

These dark and brighter pixels of the background (with labels −1 or −2), as well as dark pixels of the lung cores (with labelled +1) are used as growing seeds in the next step.

c) The modified Watershed segmentation is used to expand the lung objects and the background by repeating the following loop until no more pixel can be added to the lung objects or the background.

   i. Start with a dark threshold DT = GL [1] and a bright threshold BT = GL [3].

   ii. In each iterative loop, slowly increment DT (max. 255) and decrement BT (min. 0) respectively.

   iii. For all CXR pixels, conditionally mark unlabelled pixels as follows:

   - If an unlabelled pixel that has a gray level lower than DT and is within the neighbourhood of pixels with labels = +1 (i.e. lung core pixels) or with labels = +2 (i.e. new lung object pixels), mark it with +2.
   - If an unlabelled pixel that has a gray level less than DT and is within the neighbourhood of pixels with labels = −1 (i.e. dark background pixels), mark it with −1.
   - If an unlabelled pixel that has a gray level higher than BT and is within the neighbourhood of pixels with labels = −2 (i.e. bright background pixels), mark it with −2.

   iv. Label all marked pixels with the values of their marks.

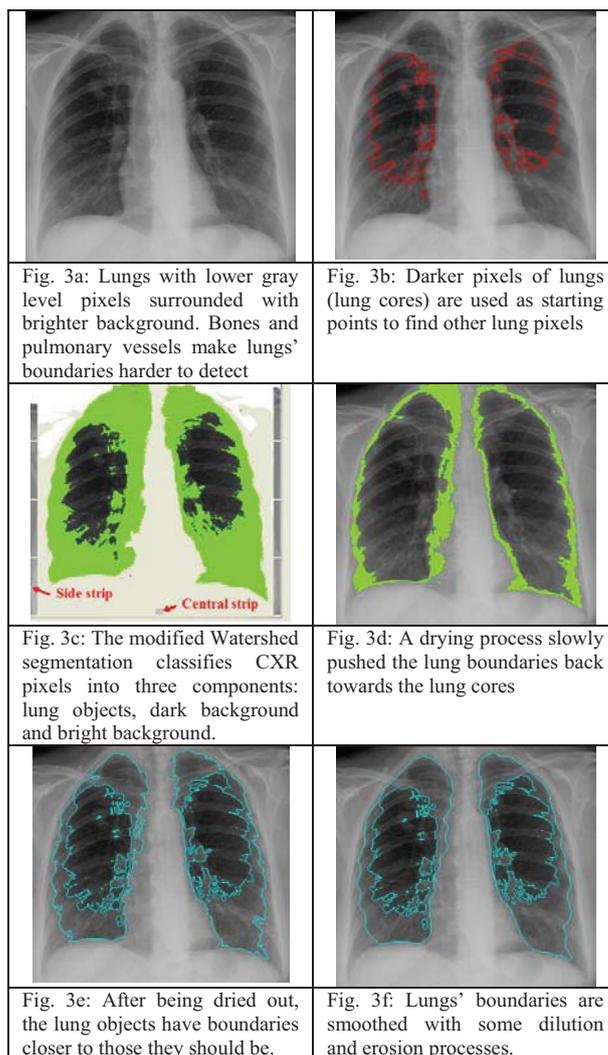   v. Repeat Steps ii, iii and iv, until no more pixel can be marked.

Fig. 3a: Lungs with lower gray level pixels surrounded with brighter background. Bones and pulmonary vessels make lungs' boundaries harder to detect

Fig. 3b: Darker pixels of lungs (lung cores) are used as starting points to find other lung pixels

Fig. 3c: The modified Watershed segmentation classifies CXR pixels into three components: lung objects, dark background and bright background.

Fig. 3d: A drying process slowly pushed the lung boundaries back towards the lung cores

Fig. 3e: After being dried out, the lung objects have boundaries closer to those they should be.

Fig. 3f: Lungs' boundaries are smoothed with some dilution and erosion processes.

Fig. 3: Chest X-ray image processing with a Watershed-based segmentation

As a result, the modified Watershed segmentation classifies CXR pixels into three components: lung objects, dark background and bright background as illustrated in Fig. 3c.

d) A slowly drying process, starting from a short vertical strip at the middle of the bottom part of CXR (Fig. 3c), is applied with a gray level being decremented until it equals a low threshold. The threshold is calculated based on the average value (G1Av) of gray levels of added lung pixels (labelled with +2) and the average value (G2Av) of all CXR pixels. For example,

$$GLThreshold = 0.75G1Av + 0.25G2Av$$

Fig. 3d illustrates the parts of expanded lung area being dried. The drying gray threshold needs more tuning for higher accuracy.

e) The boundaries of the dried lung objects (Fig. 3e) are lastly smoothed by repeating some (say 5) dilution and erosion processes. The final result is illustrated in Fig. 3f.

Once the lung objects have been detected, they can be analysed for abnormalities, some of them are presented in next sub-sections.

B. *Thoracic Diameter Measurement*:

An internal thoracic diameter is measured from the right atrial boundary of a heart to its left ventricle apex. The starting of a congestive heart failure can be detected when the cardio-thoracic ratio becomes greater than 50% [9].

The thoracic diameter can be measured as follows.

Thoracic Diameter Measurement Algorithm:

a) Apply the "Lung Boundary Detection" algorithm to find the boundaries of the left and the right lungs.

b) Draw a rectangle enclosing each lung (called the lung box –Fig. 4a).

c) Start from the bottom edge of a lung box that has the bottom edge higher than that of the other. For example in Fig. 4a, the box on the right hand side (i.e. the box of the left lung) has the bottom edge higher. Normally the box of the right lung has a higher bottom edge (Fig. 4b).

d) Detect the inner bottom corner of the lung (left lung –Fig. 4a or right lung –Fig. 4b). For example in Fig. 4b, consider several pixels (e.g. 3) on the inner boundary of the right lung at some consecutive heights above the bottom edge of the lung box. The corner is detected when there is a sharp bend on the boundary.

e) From the corner, draw a horizontal segment to the closest boundary of the other lung (e.g. of the left lung in Fig. 4b). The length of the segment is the thoracic diameter.

f) The cardiothoracic ratio is calculated as the percentage of thoracic diameter compared to the base of the common box of the two lungs.
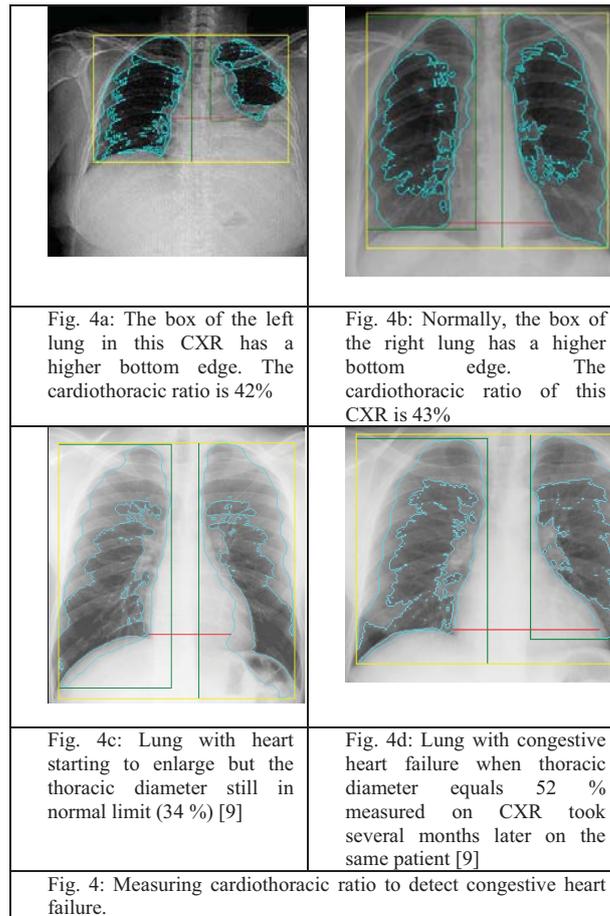
Fig. 4c & d illustrate two CXR images of the same patient, of which, Fig. 4d was taken when the patient heart was detected being enlarged with the cardiothoracic equal to 52%. In Fig 4c, the CXR taken several months earlier, the ratio is 34%. Most CXR images without heart congestion failure have the cardiothoracic ratio less than 45%. Hence it is necessary to examine patients more regularly when their ratios approaching higher 45%.

The CXR in Fig. 4a has the cardiothoracic ratio within normal range ($\leq$ 45%). However, there is abnormality in the CXR: lung collapse, which will be discussed in the next sub-section.

C. *Lung Collapse:*

Lung collapse or atelectasis is a condition where the alveoli are deflated, as distinct from pulmonary consolidation, due to alveolar collapse or fluid consolidation. It may affect part or all of one lung.

Lung collapse can be detected by measuring the volume of each lung. With CXR, the volume is estimated by counting the number of lung pixels. For example, with the CXR in Fig. 4a, the ratio between the volumes of the right and the left lungs is 211%. For normal lungs, this ratio should be about 100%, e.g. 103% for CXR in Fig. 3. The volume ratio may be also considered as a feature for diagnosis of heart failure. For example, in Fig 4d, the ratio between its two lungs is 126%.

Fig. 4a: The box of the left lung in this CXR has a higher bottom edge. The cardiothoracic ratio is 42%

Fig. 4b: Normally, the box of the right lung has a higher bottom edge. The cardiothoracic ratio of this CXR is 43%

Fig. 4c: Lung with heart starting to enlarge but the thoracic diameter still in normal limit (34 %) [9]

Fig. 4d: Lung with congestive heart failure when thoracic diameter equals 52 % measured on CXR took several months later on the same patient [9]

Fig. 4: Measuring cardiothoracic ratio to detect congestive heart failure.

The ratio between the numbers of pixels of a lung and its lung box is also a good feature for CXR diagnosis, and need further investigation. For example, with the lungs in Fig. 4a, the ratio for the right lung is 64% and the left lung is 59%. For the lungs in Fig. 3, the ratios are 70% and 63% respectively. However, for the lungs in Fig. 2d, the ratios are 58% and 64%. The ratio between the number of pixels of a lung core and that of the lung is also a feature for CXR diagnosis.

D. *Detect TP and Cancer Nodules:*

Most cancer and TB (tuberculosis) cases start with the appearance of small nodules, which can be benign or malignant with malignant nodules growing up quicker. Nodule pixels are often brighter than the surrounding areas, especially calcified parts, but in some cases, the difference in gray levels is not significant. Furthermore, ribs and pulmonary arteries, which often have higher gray levels, also contribute to the complexity of lung tissue and make some nodules being undetectable (Figure 5a). In up to 30% of cases, nodules are overlooked by radiologists on their first examinations [10], although they are visible in retrospect, especially when computer-aid diagnostic tools are used to focus radiologists' attention on suspected areas [4].

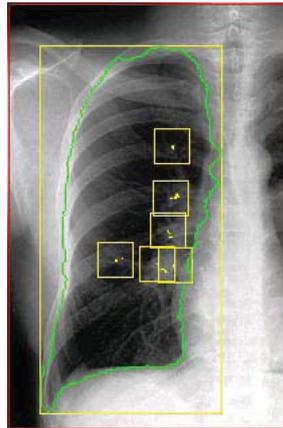Fig 5a: CXR image with some small nodules.

Fig. 5b: Nodules detected by an E-health program.

Fig. 5: Detection of nodules, which are difficult to detect due to the presence of ribs and pulmonary arteries.

To detect early nodules we use the following algorithm [5]:

Early Nodule Detection Algorithm:

a) Use the "Lung Boundary Detection" algorithm to isolate a lung object from the background.

b) Apply a small fixed size window −called scanning window− to every pixel inside the lung object, which has not been marked as part of suspected nodules.

c) Find the average and the maximal gray levels of the pixels within the scanning window. Select a local gray-level threshold between the average and the maximal levels.

d) Count the number of pixels that have gray levels higher than the local threshold. If the counted number is within a specific range then mark the pixel as part of a suspected nodule.

Figure 5b is the result obtained with the above algorithm. Preliminary experimental results obtained on ten CXR were very encouraged with the judgement of a medical professional [8]. At least 50% of nodules were correctly detected, and at most 25% of nodules were overlooked. We are tuning the algorithm with 100 CXR images collected from hospitals [11, 12].

E. *Other CXR Analysis*:

More works on lateral CXR analysis as well as detection of silhouette sign caused by mass opacity heart oversize, etc. are in progress.

IV. CONCLUSION

This paper presents the design of an active distributed E-health system. The system is scalable and more advanced softwares can be easily added. Some works on CXR analysis are presented to demonstrate the capabilities of the system as CAD tools for some chest diseases like congestive heart failure, lung collapse, etc. The experimental result obtained with an algorithm to detect early nodules for lung cancer and TP is very encouraging. Data mining and other artificial intelligent techniques may be used to make the system becoming an active and powerful expert system [1].

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