An Improved Automatic Computer Aided Tube Detection and Labeling System on Chest Radiographs

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ABSTRACT

Tubes like Endotracheal (ET) tube used to maintain patient's airway and the Nasogastric (NG) tube used to feed the patient and drain contents of the stomach are very commonly used in Intensive Care Units (ICU). The placement of these tubes is critical for their proper functioning and improper tube placement can even be fatal. Bedside chest radiographs are considered the quickest and safest method to check the placement of these tubes. Tertiary ICU's typically generate over 250 chest radiographs per day to confirm tube placement. This paper develops a new fully automatic prototype computer-aided detection (CAD) system for tube detection on bedside chest radiographs. The CAD system is based on generating tube candidates from multiple seed points and using a voting scheme to identify the tube(s). The CAD algorithm is designed as a 5 stage process: Preprocessing (removing borders, histogram equalization, anisotropic filtering), Anatomy Segmentation (to identify neck, esophagus, and abdomen ROI's), Seed Generation, Region Growing and Tube Selection. The preliminary evaluation was carried out on 64 cases. The prototype CAD system was able to detect ET tubes with a True Positive Rate of 0.93 and False Positive Rate of 0.02/image and NG tubes with a True Positive Rate of 0.84 and False Positive Rate of 0.02/image respectively. The results from the prototype system show that it is feasible to automatically detect both tubes on chest radiographs, with the potential to significantly speed the delivery of imaging services while maintaining high accuracy.

Keywords: Tube Detection, Tube Identification, Endotracheal Tube, ET tube, NG tube, Nasogastric Tube, Computer Aided Detection, Chest Radiographs, Intensive Care Unit (ICU)

1. INTRODUCTION

Computer-Aided Detection systems aid physicians in disease detection and improve their diagnostic accuracy. Traditionally, CAD was primarily designed for oncology tasks to aid physicians in identifying subtle nodules, lesions etc. However, CAD holds much promise in aiding radiologists in routine clinical tasks. We present one such application where CAD can help radiologists in detecting tubes in ICU patients. The two most often used catheters especially in the ICU's are the Endotracheal (ET) tube and the Nasogastric (NG) tube. The endotracheal tube is placed to aid the patient in breathing and to keep the trachea open and at times it is also used to administer drugs. The tip of the endotracheal tube should be placed about 5 cms above the carina, incorrect placements typically include the tube being placed in the esophagus or in the soft tissue of the neck [1]. The Nasogastric tube is primarily used for feeding and administering drugs. It can also be used to drain the contents of the stomach which may be necessary in case of poisoning or in preparation for surgery. Incorrect placement of the tube for example in the pleural cavity can cause pneumothorax. So, detecting tube placement is critical for patient's in ICU's as incorrect tube placements can cause serious complications and can even be life threatening [1]. Chest radiographs are the quickest and safest method to check placement of these tubes. Tertiary ICU's typically generate hundreds of chest radiographs per day to confirm tube placement in patients. Radiographs of patients in ICU's are often cluttered with different tubes providing life support and wires monitoring the patient vital signs, some outside and some inside the body. This makes the task of identifying these tubes a difficult and time consuming process for radiologists. The objective of this work is to design a CAD system to automatically detect and classify catheters with minimal change to the radiology workflow.

Prior systems have been either: (a) semi-automatic [2], requiring user input; or (b) automatic detecting a single tube [3] but suffer from significant false positive rate [4]. Our earlier work on CAD for tube detection [5] used a combination of template matching and morphological operations. However, this approach didn't offer satisfactory sensitivity and

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specificity measures. This paper presents an alternative fully automatic CAD prototype designed to detect and classify tubes on Chest Radiographs using a more robust algorithm based on generating tube candidates from multiple seed points and using a voting scheme to identify the tube(s). In contrast to previous studies, this study includes testing on images containing multiple tubes in close proximity and control images with no tubes.

2. METHODS

Our CAD algorithm accepts chest radiographs (typically from bed-side ICU portable x-ray stations) and generates the annotation layer for labeling and tracing tubes. The CAD system comprises of 5 stages: Preprocessing, Anatomy Segmentation, Seed Generation, Region Growing and Tube Selection. The flowchart in Fig 1 lists all the processes at each stage.

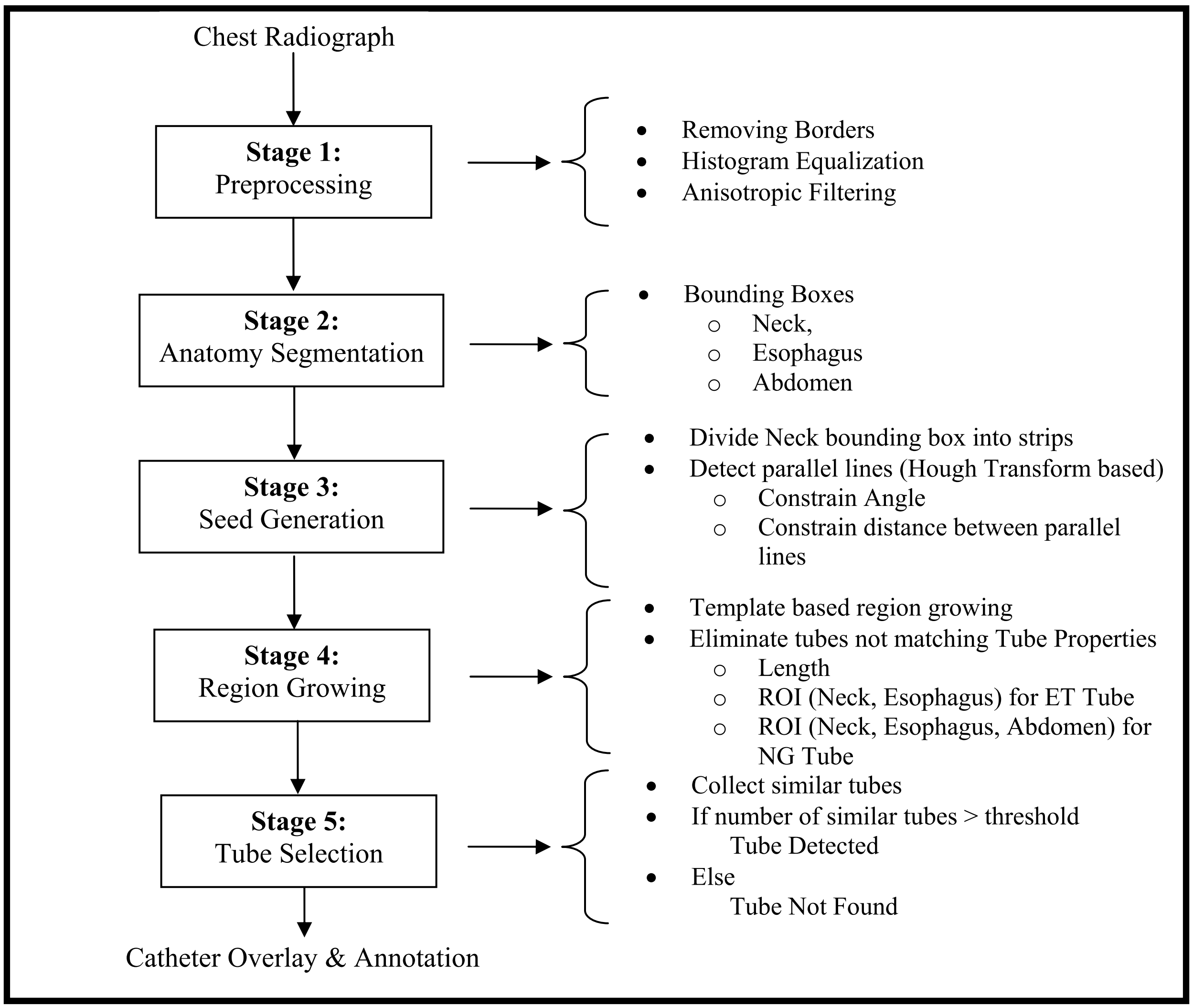


Fig 1. Flowchart of the prototype CAD system for catheter detection and classification

Stage 1: Preprocessing

Border Removal: Bedside chest radiographs usually contain borders that need be removed before further processing. This is accomplished by thresholding the image based on the intensity of the image, followed by connected component analysis to remove objects with the greatest area which is the border.

Contrast Adjustment: After the removal of borders the image is enhanced by using CLAHE [6] (Contrast Limited Adaptive Histogram Equalization) – which enhances the regions of low contrast and anisotropic diffusion [7] further enhances the image while preserving tube/catheter edges.

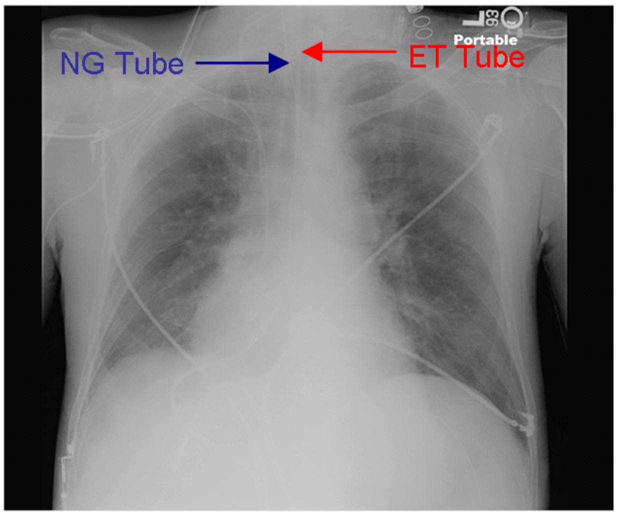


Fig 2. Source Radiograph

Fig 3. Pre-processed Image after Border Removal & Contrast Adjustment (-ive image)

Stage 2: Anatomy Segmentation

Identifying approximate anatomy location is useful in both seed generation and elimination of false positives. Approximate bounding boxes are computed for each anatomy (Neck, Esophagus and Abdomen) by employing template matching. Rectangular templates are constructed for the Neck, Esophagus and Abdomen. Relative positions of the ROI's are taken into account to optimize the placement of the bounding boxes as shown in Fig 4.

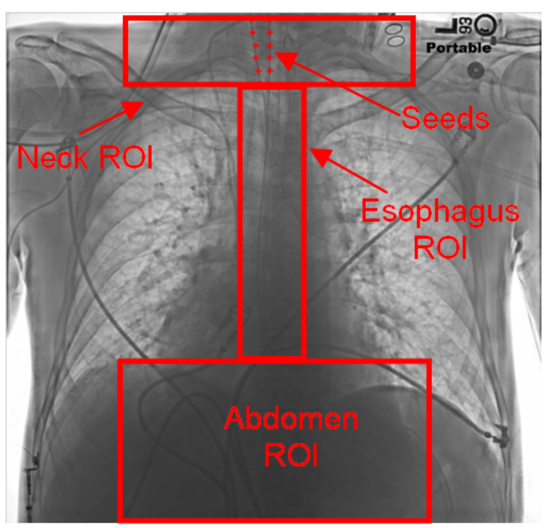


Fig 4. Anatomy Segmentation & Generated Seeds (ROI Neck)

Stage 3: Seed Generation

Multiple seeds (as shown in Fig. 4) are generated in the Neck ROI to be used for region growing. This is accomplished by dividing the Neck ROI into strips and identifying parallel lines on the gradient image. Once the parallel lines have been identified the seed location is taken as the mid-point between the parallel lines. Seeds are generated by using both the ET Tube and NG Tube profiles as parameters and the orientation is limited to being close to perpendicular w.r.t x-axis of the image. However, the generated seeds are not labeled as ET seeds or NG seeds.

Stage 4: Region Growing

Region Growing: Region growing is carried out on all the generated seeds from the previous stage using template matching. The templates are designed as a function of the tube profile. Template matching accepts orientation, translation and tube profile as parameters and returns matched orientation and translation. The stopping rule for region growing is that the template match score is contiguously below a given threshold.

Tube Exclusion: Tubes are excluded if they do not meet the length and location properties of the particular tube. For the case of the ET tube, the location is limited to the Neck and Esophagus ROI's and for the case of NG tube, the location is limited to the Neck, Esophagus and Abdomen ROI's.

Stage 5: Tube Selection

Tubes segmented via region growing are grouped based on tube type. An intra-comparison is performed to identify similar tubes w.r.t. location. If no similar tubes are found for a particular type then CAD declares that the tube as undetected. The confidence of tube detection is function of the number of similar tubes identified.

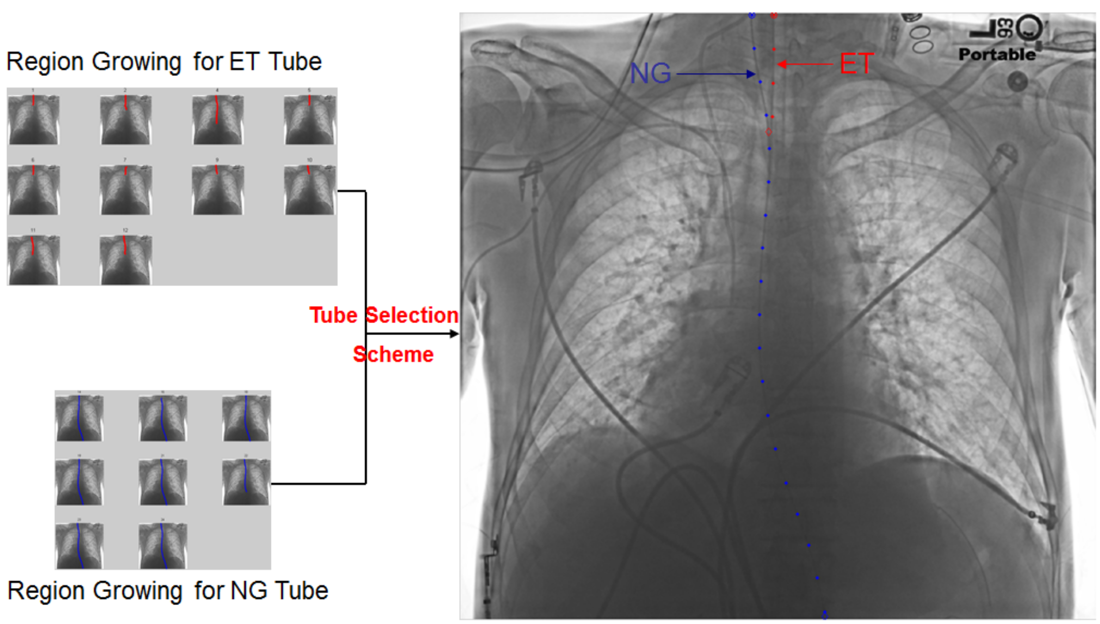


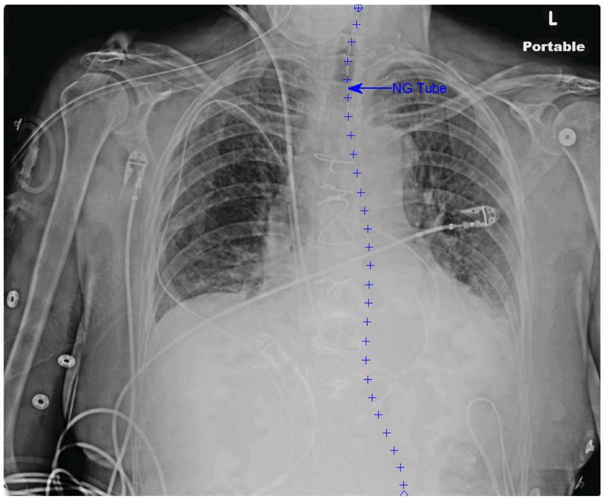
Fig 5. Region Growing & Tube Selection

3. RESULTS

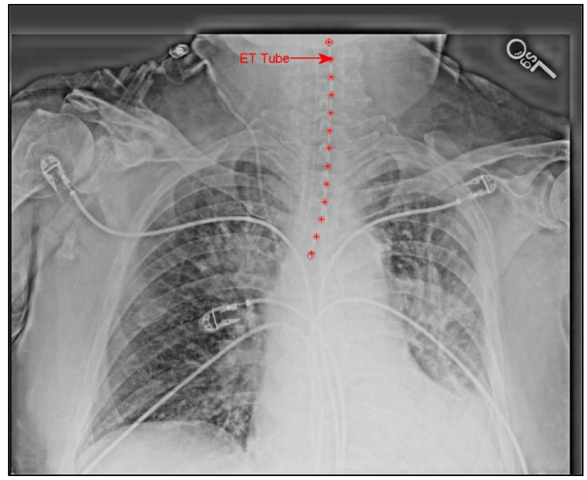
With IRB approval we identified 64 chest radiographs obtained from 52 patients. Of these, 20 had both ET tube and NG tubes, 5 with only NG Tube, 8 with only ET tube, and 31 had no tubes. The prototype CAD system performance is shown in Tables 1 for ET and NG tubes. The CAD system was able to detect ET tubes with a True Positive Rate (TPR) of 0.93 and False Positive Rate (FPR) of 0.02/image. For the NG tube, the True Positive Rate (TPR) was 0.84 and False Positive Rate of 0.02/image. Figure 6 shows some sample CAD output results.

Table 1. CAD System performance (Number of True Positives & False Positives)

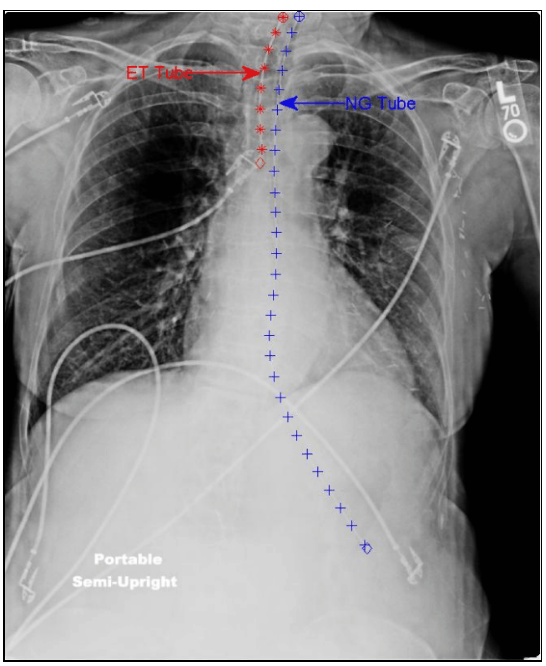
Tube Type	True Positives	False Positives
ET	26	1
NG	21	1



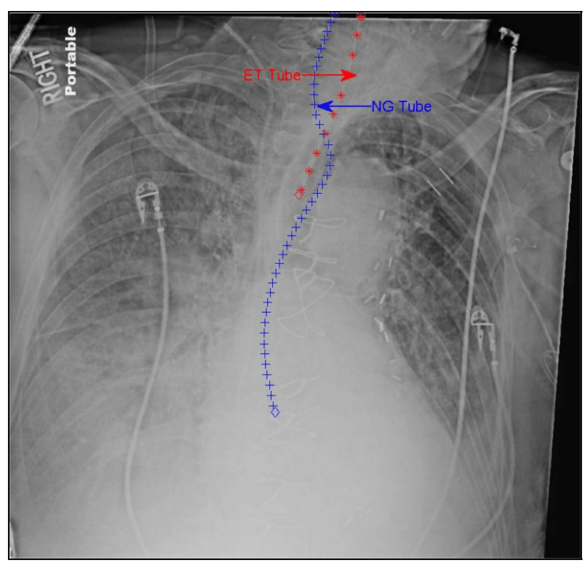
(a)



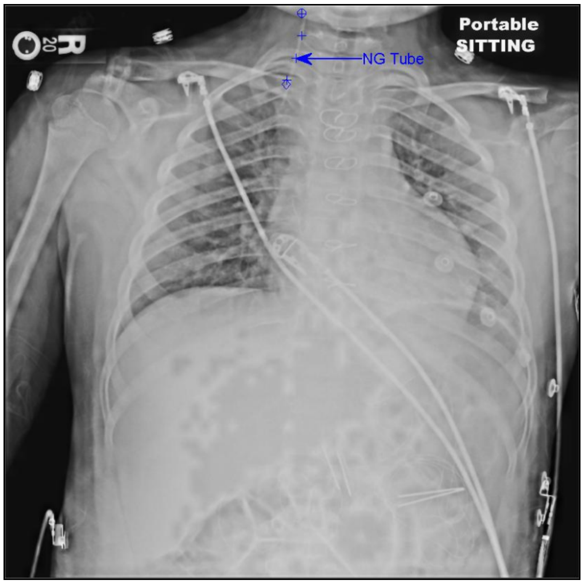
(b)



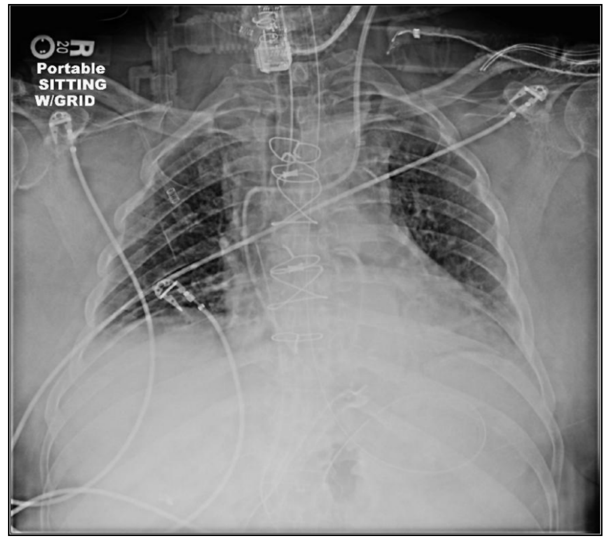
(c)



(d)



(e)



(f)

(Note: ET tube is represented as red '' and NG tube is represented as blue '+')*

Fig 6. Sample images showing prototype CAD results **(a)** NG tube present and detected **(b)** ET tube present detected **(c)** both tubes present and detected **(d)** both tubes present and detected **(e)** NG tube detected wrongly (false-positive) **(f)** both tubes present but missed by CAD

4. CONCLUSION

Chest radiographs are used to confirm placement of life support tubes in patients, and incorrect placement of these tube can cause severe complications and can even be fatal. Assessing tube placement on chest radiographs is a difficult, time consuming task for radiologists and ICU personnel, given the high volume of cases and the need for rapid interpretation. There has been very little research on detecting catheters, tubes and wires in chest radiographs, despite the significant clinical need. Prior systems have been either: (a) semi-automatic or (b) automatic approaches but both suffering significant false positive rate. In an earlier work we presented a novel prototype CAD algorithm using a combination of template matching and morphological operations, this system though novel didn't offer satisfactory sensitivity and specificity measures. In this work, we present an alternate novel CAD approach based on generating tube candidates from multiple seed points and using a voting scheme to identify the tube(s) on chest radiographs with improved true positive rate (TPR) and false positive rate (FPR). The CAD results show good performance in terms of TPR and FPR in images with no tubes and images containing multiple tubes in close proximity. The results from the prototype system show that it is feasible to automatically detect both ET tube and NG tube on chest radiographs, with the potential to increase radiologist productivity and confidence, and to improve patient safety.

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