SYSTEM AND METHOD FOR FACILITATING INSPECTION OF NASOGASTRIC INTUBATION IN A TARGET SUBJECT

TECHNICAL FIELD

[0001] The present disclosure relates to systems and methods for facilitating inspection of nasogastric intubation in a target subject.

BACKGROUND

[0002] In April 2004, an inquest was held into the unexpected death of an eight-year-old girl in an NHS hospital in England. She had required intubation and ventilation due to respiratory failure and was temporarily unable to eat or drink. A nasogastric tube was passed to administer enteral feed. The position of the tube was checked with the whoosh test (auscultating the epigastrium for bubbling as air is injected down the tube) and litmus testing of the aspirate. The whoosh test was positive while the aspirate from the tube turned blue litmus paper pink, suggesting gastric acidity. The tip had in fact punctured the pleura to lie in the pleural cavity. When enteral feed was administered through the tube her respiratory function worsened. The whoosh and litmus paper test were repeated, appearing to confirm the positioning of the tube in the stomach. Feeding continued and the girl died. Following the inquest, the coroner, under his statutory powers, issued a notice to the NHS. He sought to avoid a recurrence and drew attention to hazards in routine clinical practice (Yardley, 2010).

[0003] Nasogastric tube insertion (intubation) is a common clinical procedure carried out by doctors and nurses in NHS hospitals daily. In the US, over 275,000 nasogastric tubes are supplied to the NHS annually (personal communication, NHS Supply Chain, May 2009). For the last 30 years, there have been reports in the medical literature of deaths, internal bleeding, and other harm resulting from misplaced nasogastric tubes, most commonly associated with food entering the pulmonary system. This is a potentially preventable error but safety alerts advocating best practice do not appear to reliably reduce risk (Yardley, 2010).

[0004] Nasogastric tubes are used for feeding, medication administration, or suction of fluids for patients with a wide variety of complications. If the patient can't eat or swallow, they may need to have a nasogastric tube inserted. This process is known as nasogastric (NG) intubation. NG intubation is most commonly used for patients who have neck or facial injuries, had neck or facial surgery, need a mechanical ventilator to breathe, have an intestinal obstruction, or blockage, or are comatose. Other conditions that can cause the patient to have trouble eating include stroke, burns, cerebral palsy, motor neuron disease, and dementia. It's also used to help treat some premature infants.

[0005] During NG intubation, a doctor or a nurse will insert a thin plastic tube through patient's nostril, down the esophagus, and into the stomach. Once this tube is in place, they can use it to give food and medicine to the patient. They can also use the nasogastric tube (NGT) to remove things from stomach, such as toxic substances, blood, or a sample of stomach contents.

[0006] Chest radiography for NGT position is commonplace in many hospitals. The aim is to positively confirm that the route and exit hole(s) of the NGT is/are within the gastrointestinal tract (usually the

stomach). The importance of establishing the position of the NGT cannot be understated. A patient who is fed or administered drugs via a malposition NGT can have very poor outcomes including iatrogenic death. X-ray confirmation of NGT position is not practiced in some centers- the position of the tip of the NGT is assessed by drawing back gastric contents and testing with PH paper.

[0007] NGTs are generally inserted via the nostril. Alternatively, an orogastric tube can be used - this tube is inserted via the patient's mouth into the stomach. A deviated nasal septum, polyps or other pathology may suggest one nostril will be more patent than the other. It is worth asking the patient which nostril is more patent. It can be helpful to check nostrils for patency by asking patient to occlude one nostril and breathe normally through the other. Select the nostril through which air passes most easily. Alternatively, ask the patient to blow their nose into a tissue.

NASOGASTRIC INTUBATION RISKS

[0008] Because of the proximity of the larynx to the esophagus, the nasogastric tube may enter the larynx and trachea (Lo et al, 2008). This may cause a pneumothorax (Zausig et al, 2008). When the tube is in the airway, it will cause severe irritation and cough, and it may cause choking, coughing, trouble breathing, internal bleeding, and turning pale. The tube may coil up in the patient's throat is particularly likely if the patient retches. The tube can enter the brain There are case reports of NG tubes perforating the base of the skull and reaching the brain (Geissler, 2007). Retropharyngeal abscess is another condition that may occur from perforation of a piriform sinus (Makay et al, 2008; Obon Azuara et al, 2007) and will cause swallowing problems. Feeding through a tube incorrectly placed in the bronchial tree may cause severe sepsis, which can be fatal.

[0009] Many hospitals have developed checklists to avoid complications related to NG tubes. Any complications that do occur should be reported on a critical incident form. Asking patients to hold some water in their mouth and swallowing it while the tube is in the throat may help to pass the tube into the esophagus. However, this solution can only be used for conscience, cooperative patient. Confused and unconscious patients may not show respiratory distress even if the tube is in the respiratory tract (Durai et al, 2009). Auscultation of the epigastric region after insufflation of air through the tube (the 'whoosh' test) is another way to check the correct intubation, where the nurse or doctor inserts air through the tube, while listening to patient's stomach with a stethoscope. However, this method is primitive, inaccurate, and passive, not allowing tracking of the tube during insertion. Therefore, literature recommends against using this method (Stock et al, 2008, Durai et al, 2009). Use of litmus paper is also an improper method as the blue litmus paper cannot distinguish between bronchial and gastric secretions so should not be used to verify the tube's correct position (Durai et al, 2009). The current recommended procedure to verify the correct position of an NG tube is by checking the aspirate for acidic pH of 5.5 or below (NPSA, 2005), and by an X-ray if necessary.

[0010] The absence of a wholly reliable test means that, in common with most medical interventions, nasogastric feeding will never be completely without risk. More than 25 years have passed since the potentially fatal complication of intrapleural feeding was first described in the medical literature. In this time, the evidence for and against methods of checking tube position has grown. Therefore, there is a pressing need for a method to easily and reliably detect the position of the NGT during the intubation process.

SUMMARY

[0011] According to a first aspect of the present invention, there is provided a method to facilitate inspection of nasogastric intubation for a target subject, the method includes: illuminating subject's throat with one or more light source, from within or outside; obtaining one or more digital images of at least a portion of subject's throat; extracting a plurality of feature vectors from the one or more digital images; and identifying, using a first trained deep neural network, the presence of NGT in the subject's airway, based on the plurality of extracted feature vectors.

[0012] In an embodiment, the method may include processing one or more digital images of one or more wavelengths (e.g. visible light, infra-red, or otherwise) emitted by a light source illuminating from within or outside the subject's throat.

[0013] In an embodiment, the method may include processing the one or more digital images of the throat for segmentation of different body parts and/or background, prior to extracting the plurality of feature vectors from the one or more digital images.

[0014] In an embodiment, the step of processing the one or more digital images of the subject's throat may include: down-sampling the one or more digital images, coarse segmentation of the down-sampled one or more digital images; and refinement of the coarse segmented one or more digital images

[0015] In an embodiment, two or more digital images of different sides of the throat may be obtained separately from two or more digital image capturing devices spaced apart from each other, and the method may further include: constructing a three-dimensional model of the subject's throat and/or airway based on the two or more digital images of the throat; processing of the two or more digital images to obtain a refined two or more digital images of the throat based on the combined information from one or more of the digital images of the throat; processing of the two or more images for segmentation of different body parts and/or background, prior to extracting the plurality of feature vectors from the one or more digital images.

[0016] In an embodiment, a second trained deep neural network may be used to facilitate construction of the three-dimensional model of the throat and/or airway.

[0017] In an embodiment, the method may further include extracting plurality of feature vectors from one or more digital images and identifying a secondary complication based on the extracted plurality of feature vectors

[0018] In an embodiment, the secondary complication may include at least one of: anomalies in tissues such as inflammation, abscess, ulcer, or cancerous tissues, anomalies in blood vessels such as blockage, and internal bleeding.

[0019] In an embodiment, the method may include processing of the plurality of feature vectors to automatically determine if the NGT passes through the airway during the intubation.

[0020] According to a second aspect of the present invention, there is provided a system for facilitating inspection of nasogastric intubation for a target subject, the system including: one or more illuminator modules configured to illuminate at least a portion of subject's airway from within or outside; one or more image capturing modules configured to obtain one or more digital images of at least a portion of the subject's throat; a processor module configured to extract a plurality of feature vectors from the one or more digital images; and a first neural network module configured to implement a first trained deep neural network for detection of the passage of the NGT through subject's throat based on the plurality of feature vectors.

[0021] In an embodiment, the processor module may be further configured to process the one or more digital images of the subject's throat for segmentation of different body parts and/or background, prior to extraction of the plurality of feature vectors from the one or more digital images.

[0022] In an embodiment, the processor module may be further configured to: perform down-sampling the one or more digital images of subject's throat; perform coarse segmentation of the down-sampled one or more digital images; and perform refinement of the coarse segmented one or more digital images, for segmentation of different body parts and/or background, and/or image illumination correction and/or sharpness.

[0023] In an embodiment, the system may include two or more digital capturing devices spaced apart from each other and configured to separate obtain two or more digital images of the subject's throat, wherein the processor module is further configured to: construct a three-dimensional model of the throat and/or airway based on the two or more digital images of the throat; process two or more digital images to obtain refined one or more digital images of the throat based on combined information from one or more digital images of the throat; and process the three-dimensional model of the throat for segmentation of the throat from other body parts and/or background, prior to extracting the plurality of feature vectors from the one or more digital images.

[0024] In an embodiment, the processor module may be further configured to detect the presence of NGT in subject's airway anytime during the intubation.

[0025] In an embodiment, the system may include a second neural network module configured to implement a second trained deep neural network to facilitate construction of the three-dimensional model of the throat and/or airway.

[0026] In an embodiment, the system may include a first neural network module configured to implement a first trained deep neural network to facilitate refinement of the one or more digital image of the throat.

[0027] In an embodiment, the one or more digital images may be further processed by the processor module to detect a secondary complication based on the plurality of extracted feature vectors.

[0028] In an embodiment, the illuminator module may be further configured to: pass through the NGT and into the subject's throat, to illuminate the NGT passage from within the subject's body.

[0029] In an embodiment, the illuminator module may be further configured to: attach, detach, or slide to the side of the NGT, and into the subject's throat, to illuminate the NGT passage from within subject's body.

[0030] In an embodiment, the illuminator module may be further configured to: cover the light source and other related components with a transparent sheath to avoid contact with bodily fluids.

[0031] In an embodiment, the illuminator module may be further configured to: include one or more safety wires to control its movement, placement, anchoring, and pull-out.

[0032] In an embodiment, the illuminator module may be further configured to: transport the light into or alongside the NGT and into the throat, with the light source placed outside of the body, using optical fibre or similar material.

[0033] In an embodiment, the illuminator module may be further configured to: illuminate the airways directly from outside of subject's body, by being places near or adjacent to the side of the throat.

BRIEF DESCTIPTION OF THE DRAWINGS

[0034] Embodiments will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

[0035] Figure 1 illustrates a flow chart describing a method for facilitating inspection of the nasogastric intubation in a target subject, during the intubation process, according to an example embodiment.

[0036] Figure 2 shows a schematic diagram illustrating the flow of information in a system for facilitating inspection of the nasogastric intubation in a target patient, according to an example embodiment.

[0037] Figure 3 shows a schematic view of the illumination module passing through subject's throat and esophagus (the correct intubation for feeding purposes) alongside the nasogastric tube, while one or more digital images being captured by one or more image capturing devices, according to an example embodiment.

[0038] Figure 4 shows a schematic view of the illumination module passing through subject's throat and trachea (the incorrect intubation for feeding purposes) alongside the nasogastric tube, while one or more digital images being captured by one or more image capturing devices, according to an example embodiment.

[0039] Figure 5 shows a schematic view of the illumination module passed through the subject's nose along with the NGT, while an image capturing module is capturing one or more digital images from the airway from the frontal or side view, according to an example embodiment.

[0040] Figure 6 shows a schematic diagram of two example embodiments for the illuminator module with an IR LED light source, power wires, safety wire, and protective sheath, and optical fibre that can

be passed through the NGT tube or alongside it, through subject's throat, according to an example embodiment.

[0041] Figure 7 shows a schematic view of the external illuminator module with an array of IR LEDs as its light source, illuminating subject's airways from one side, while the image capturing module captures one or more digital images from the other side, during the intubation process, according to an example embodiment.

[0042] Figure 8 illustrates a flow chart demonstrating a method of training a first deep neural network, according to an example embodiment.

[0043] Figure 9 shows a schematic diagram of a computer device / system, suitable for realizing a module, according to an example embodiment.

DETAILED DESCRIPTION

[0044] Some portions of the description which follows are explicitly or implicitly presented in terms of algorithms and functional or symbolic representations of operations on data within a computer memory. These algorithmic descriptions and functional or symbolic representations are the means used by those skilled in the data processing arts to convey most effectively the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self-consistent sequence of steps leading to a desired result. The steps are those requiring physical manipulations of physical quantities, such as electrical, magnetic or optical signals capable of being stored, transferred, combined, compared, and otherwise manipulated.

[0045] Unless specifically states otherwise, and as apparent from the following, it will be appreciated that throughout the present specification, discussions utilizing terms such as "scanning", "calculating", determining", "replacing", "generating", "initializing", "outputting", "identifying", "authorizing", "verifying" or the like, refer to the action and processes of a computer system, or similar electronic device, that manipulates and transforms data represented as physical quantities within the computer system into other data similarly represented as physical quantities within the computer system or other information storage, transmission or display devices.

[0046] The present specification also discloses apparatus for performing the operations of the methods. Such apparatus may be specially constructed for the required purposes or may comprise a computer or other device selectively activated or reconfigured by a computer program stored in the computer. The algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various machines may be used with programs in accordance with the teachings herein. Alternatively, the construction of more specialized apparatus to perform the required method steps may be appropriate. The structure of a computer will appear from the description below.

[0047] In addition, the present specification also implicitly discloses a computer program, in that it would be apparent to the person skilled in the art that individual steps of the method described herein may be put into effect by computer code. The computer program is not intended to be limited to any particular programming language and implementation thereof. It will be appreciated that a variety of programming languages and coding thereof may be used to implement the teachings of the disclosure contained herein. Moreover, the computer program is not intended to be limited to any particular control flow. There are many other variants of the computer program, which can use different flow without departing from the spirit or scope of the disclosure.

[0048] Furthermore, one or more of the steps of the computer program may be performed in parallel rather than sequentially. Such a program may be stored in any computer readable medium. The computer readable medium may include storage devices such as magnetic or optical disks, memory chips, or other storage devices suitable for interfacing with computer. The computer readable medium may also include a hard-wired medium such as exemplified in the Internet system, or wireless medium such as exemplified in the GSM mobile telephone system. The computer program when loaded and executed on such a computer effectively results in an apparatus that implements the steps of the preferred method.

[0049] Figure 1 illustrates a flow chart 100 demonstrating a method for facilitating inspection of nasogastric intubation in a target subject, according to an example embodiment. At step 102, one or more digital images are obtained of at least a portion of subject's throat. At step 104, a plurality of feature vectors are extracted from the one or more digital images. At step 106, the NGT is localized, using a first trained deep neural network, based on the plurality of extracted feature vectors. At step 106, secondary complications may also be detected using a first trained deep neural network, based on the plurality of extracted feature vectors.

[0050] The method may further comprise processing the one or more digital images of the subject's throat for segmentation of different body parts and/or background prior to extracting the plurality of feature vectors from the one or more digital images. The step of processing the one or more digital images of the subject's throat for segmentation may comprise: down-sampling the one or more digital images of the subject's throat; coarse segmentation of the down-sampled one or more digital images; and refinement of the coarse segmented one or more digital images. Two or more digital images may be obtained separately from two digital images capturing devices spaced apart from each other. The method may further comprise: constructing a three-dimensional model of the subject's throat and/or airway based on the two or more digital images of the throat; and processing the three-dimensional model of the throat and/or airway for segmentation of body parts and/or background prior to extracting the plurality of feature vectors from the one or more digital images.

[0051] The method may also further comprise construction of the three-dimensional model using a second trained deep neural network to facilitate three-dimensional model construction. The method may also include extracting plurality of feature vectors from one or more digital images of the subject's throat and identifying a secondary complication based on the plurality of the extracted feature vectors. The secondary complication may include at least one of: anomalies in tissues such as inflammation, abscess, ulcer, or cancerous tissues, anomalies in blood vessels such as blockage, and internal bleeding.

[0052] Figure 2 shows a schematic diagram illustrating the flow of information in a system 200 for facilitating inspection of nasogastric intubation in a target subject. The system 200 comprises a processor module 202, a first neural network module 204, a second neural network module 206, a database 210, an image capturing module 208, and an illuminator module 212. The image capturing module 208 is configured to obtain one or more digital images of at least a portion of subject's throat. The processor module 202 is configured to extract a plurality of feature vectors from the one or more digital images. The first neural network module 204 is configured to implement the first neural network for localization of the NGT in a target subject's throat during intubation based the plurality of extracted feature vectors. The illuminator module 212 is configured to illuminate at least a portion of subject's throat or airway, internally or externally. The image capturing module 208 is in communication with the processor module 202, which in turn is in communication with the first neural network module 204, the second neural network module 206 and the database 210.

[0053] At step A in Figure 2, the image capturing module 208 captures digital images of the subject's throat while the illuminator module 212 is illuminating at least a portion of subject's throat or airway using one or more light sources from either within or outside the throat. The digital images may include one or more visible-light images and/or one or more IR or near-IR (NIR), or any other suitable electromagnetic wave images and the image capturing module 208 may be integrated with a smartphone. The image capturing module 208 may comprise two or more digital image capturing devices spaced apart from each other and configured to separately obtain two or more digital images of the subject's throat. The digital images are subsequently sent to the processing module 202 at step B in Figure 2 for segmentation of body parts and/or background in the digital images.

[0054] Image segmentation is performed using visual features of isolated object or objects separated by boundaries to partition an image into several segments. Image segmentation is needed to locate the region-of-interest for analysis and assessment of the digital image and localization of the NGT. In particular, the body parts and/or background may be needed to be initially localized in the received digital images, for example visible-light images, before other analysis required for localization of the NGT can be performed. Accordingly, image segmentation has to be performed under simultaneous memory and computation constraints of portable devices, such as smartphones.

[0055] In an implementation, image segmentation involves pixel-domain down-sampling of the digital images and includes two main steps: Firstly, coarse segmentation is performed on the down-sampled digital images and secondly, refinement is then applied to the coarse segmentation results of the digital images. In addition, a framework is provided which may enable competitive accuracy for image segmentation. The framework may include examining the effect of down-sampling on segmentation using a signal processing analysis. Such an analysis may determine the uncertain regions on body parts and/or background, for example, small image regions where pixel labels are uncertain after the coarse segmentation. Further, an efficient Minimum Spanning Tree (MST)-based algorithm is applied to propagate the labels into the uncertain regions. Such a framework and method of image segmentation not only may improve segmentation accuracy, but may use less computation time and memory than existing methods, thereby making it suitable for image analysis applications on portable devices.

[0056] Further, the processor module 202 may also construct a three-dimensional model of the subject's throat and/or airway based on two or more digital images and process the three-dimensional model of the throat and/or airway for segmentation of body parts and/or background prior to extracting plurality of feature vectors from the one or more digital images.

[0057] A full three-dimensional model of the subject's throat and/or airway can be reconstructed because of the presence of a stereo vision. This may be possible by having two or more digital images capturing devices with known or calculatable distance from each other to capture images or the throat or airway, and the three-dimensional model can be reconstructed using camera intrinsic properties and triangulation approach.

[0058] In an embodiment, a compressed second neural network module 206 may be configured to implement a second trained deep neural network to facilitate construction of the three-dimensional model of the throat and/or airway in order to construct a three-dimensional model estimation of the throat and/or airway on a portable device (see Step C of Figure 2). For example, the second neural network module 206 may be running on the portable device together with the processor module 202. The second trained deep neural network may be compressed into the architecture of the smartphone such that the processor module 202, together with the second neural network module 206, and may be able to rapidly estimate the three-dimensional model on the phone with lower energy consumption.

[0059] Alternatively, the second trained deep neural network may be located in a server (not shown in Figure 2). As more computational power and energy is available on the server, a higher definition three-dimensional model may be achieved from the two or more digital images obtained from the two or more digital image capturing devices. The three-dimensional model of the throat and/or airway may be constructed from a video of the throat or airway captured by the portable device (e.g. a smartphone) using structure from motion (SfM). Specifically, a fast and accurate three-dimensional model reconstruction of small-scale objects may be achieved for this application the following method as described below.

[0060] First, relative camera poses between different two-dimensional images need to be estimated. Second, based on the estimated poses, the image points on the two-dimensional images can be back-projected rays determined the three-dimensional points and the reconstructed three-dimensional model. In this method, improving the estimation of relative camera poses may be the most important factor to achieve good accuracy in SfM.

[0061] Relative camera poses estimation involves several steps. In particular, a robust model estimation algorithm needs to be applied to estimate the relative geometric transformation between the two-dimensional images and remove outlier correspondences. Embodiments include applying sophisticated sampling and model checking and verification to significantly improve the accuracy in model estimation and reduce the computational complexity.

[0062] In addition, current smartphone gyroscope and accelerometer sensors can produce crude values for camera intrinsic parameters. Many digital cameras also embed focal length and other information in the exchangeable image file format (EXIF) tags of image files. Such information can be used at the server implementing the second trained deep neural network to capture rough camera movements and therefore increase the speed of convergence by setting value limits to the amount each pixel could have been moved from one digital image to another. This limit significantly reduces the point matching time at the server side.

[0063] At step C of Figure 2, the processor module 202 may localize or indicate the presence of the nasogastric tube in the subject's throat, using the segmented three-dimensional model. The segmentation may be attained from the combination of segmented digital images of the subject's throat (step B of Figure 2) and construction of the three-dimensional model of the subject's throat and/or airway (step C of Figure 2).

[0064] More specifically, a plurality of feature vectors from the digital images may be extracted. For example, each three-dimensional point is associated with one or more local feature descriptors or vectors (e.g. using scale-invariant feature transform, SIFT). Local features in the in the two-dimensional images can be matches against those of the three-dimensional points. This matching registers the two-dimensional images onto the three-dimensional model. After the two-dimensional images are registered, the body part and/or background boundaries can be identified in the two-dimensional images or three-dimensional model based on the segmentation results.

[0065] Active corresponding search may be used in this regard for two-dimensional to three-dimensional feature matching, which may reduce computational complexity. In addition, current smartphone gyroscope and accelerometer sensors can produce crude values for camera intrinsic parameters and movements. Many typical digital cameras also embed focal length and other information in the EXIF tags of image files. Such information may be used at the server to capture rough camera movements and therefore increase the speed of convergence by setting value limits to the amount each pixel could have been moved from one image to another. The value limits may

significantly reduce the point matching time at the server side. Thereafter, three-dimensional model, segmentation, and other feature extraction processes can be attained.

[0066] At step D of Figure 2, after feature vectors are extracted, a first deep neural network module 204 that is configured to implement the first trained deep neural network localize or indicate the presence of the NGT in the subject's throat based on the plurality of extracted feature vectors.

[0067] Localization of the NGT in the subject's throat during the intubation process is an important and vital part of the process to avoid complications. Embodiments advantageously enable localization or indication of presence of NGT in the subject's throat using imaging techniques.

[0068] The system as claimed may detect the presence of NGT in subject's throat using the first deep neural network. In other works, the first trained deep neural network may be used as either an image segmentation tool, or an image classifier tool such that it is a max-pooling conventional neural network. The first trained deep neural network takes one or more digital images that may accompany segmentation masks as input. The images may be visible light, near-IR, IR, or any similar or combination of similar wave-lengths. The first trained deep neural network performs down-sampling pooling, up-samples, and full sweep on the input, at different layers. The first trained deep neural may output a segmented output indicating the location of the NGT as an intermediate step, before outputting the detection of presence of NGT. The first trained deep neural network automatically learns a set of features from the training data. Thus, using a proper and large enough training dataset, first trained deep neural network can mine rich and discriminative features beyond color and texture for this segmentation / classification task. Alternatively, these processing steps may be performed individually, using separate image processing steps, but may require higher computational and/or energy cost which may not be suitable for portable devices.

[0069] The following method addresses typical problems in training deep neural networks to localize or identify the presence of NGT. An example of a problem includes training such deep neural networks on limited number of medical data, without facing the overfitting problem. Another example is to compress the resulting trained deep neural network to run them on a smartphone that has limited computational power, memory, or energy.

[0070] The first step of the method is to train the first deep neural network based on how the human brain perceives images. Humans perceives color of an object to be similar under different lighting conditions, which is a result of a process in the primary visual cortex that also shown in "color illusion experiments". In order to replicate such a perception consistency, the first deep neural network is trained using several thousand images that have the same scene under different illuminations (as shown in Section X of Figure 8). These images are unrelated to the localization of NGT, but containing information about the different illumination conditions using the light source that is used in the illumination module, to help the first deep neural network to learn the concept of color consistency under different illumination conditions.

[0071] Subsequently, the first deep neural network is trained on general object detection using over 1.2 million images of several different objects (unrelated to the task of localizing NGT tube) from a public image database (for example ImageNet) as shown in Section Y of Figure 8. This trains the first deep neural network to acquire feature extraction steps, required for general "object" detection, including lines, curves, color, textures, etc. As the first deep neural network is now trained to be robust under different illumination conditions and general characteristics of an "object", the first deep neural network is trained specifically on throat images to fine-tune the higher-level decisions in the network on distinguishing different possible outcomes (See Section Z of Figure 8).

[0072] A joint segmentation-localization analysis approach may also be used to train the first deep neural network. More specifically, in the body part and/or background segmentation, over segmentation of the image parts is carried out to obtain smaller partitions of the body / background. Each partition may be normalized in size and then passed directly into the first deep neural network for localization / classification of presence of NGT in the input.

[0073] The first deep neural network can be trained such that the image refinement, feature extraction, body part / background segmentation, NGT localization, and NGT presence detection may be included in a single architecture. The first deep neural network can receive the corresponding images in different wavelengths as well as coarse segmentation masks as an additional channel to the visible or IR light image so that it may achieve better segmentation/classification results. It is also possible to receive an IR signature directly from the visible light digital camera without any other specific image capturing devices. This can be accomplished by either removing the IR filter on a normal digital camera or training the first deep neural network to learn the transformation from the input from normal digital camera to an intermediate image estimating the captured image as if it was captured by an IR camera.

[0074] In order to run the network efficiently on a portable device (such as a smartphone), the first deep neural network may be compressed through quantization and hashing of variables which can significantly compress the network size, which also increases its speed.

[0075] In an alternative embodiment, two-dimensional image synthesis may be used to augment the training dataset: Using such a method, the same training image captured by the camera can be synthesized under different lighting conditions, with different devices, and in different camera settings, and thus creating different images with possibly different characteristics. By estimating how the throat looks like under these different conditions, the training database size can be increased exponentially. Image processing methods and computational photography fields may be used for synthesizing images in the training dataset. In other words, an image taken by a certain device and using a certain camera setting may be transferred to any other device and in any camera settings.

[0076] In yet another embodiment, realistic motion blur synthesis may be used as a set of images to the image database. This is because of the nature of portable devices that are prone to motion-blur, and therefore the first trained deep neural network should handle this type of imaging artefact. Typical de-blurring techniques include using real motion kernels, recorded using accelerometers. These motion kernels can be used to re-generate blurred images from original database images, as if there were actually capture while the portable device was moving. This set of synthesized images can not only help increase the image database size, it can also train the first deep neural network to be robust against moderate artefacts. The same approach can be applied to other types of imaging artefacts such as noise and poor/extreme lighting.

[0077] At step E in Figure 2, the processor module 202 may be configured to extract features to identify a secondary complication based extracted data visible light, near-IR, IR, etc. images. The secondary complication may comprise at least one of: anomalies in tissues such as inflammation, abscess, ulcer, or cancerous tissues, anomalies in blood vessels such as blockage, and internal bleeding.

[0078] Different body tissues and bodily fluids absorb are different in absorbing different wavelengths. Therefore, tissue types and bodily fluids can be detected based on the residual light, in the one or more captured images.

[0079] In an embodiment, a large volume of data with visible, near-IR, IR, or similar images and the corresponding state of complications in the subject's throat region (including normal samples) are collected. Subsequently, correlation is carried out with the collected data with different medical conditions. Based on a limited number of labelled images, a significantly larger unlabelled set of images may be used to further train the first deep neural network to detect complications in the subject's throat, based on the one or more digital images.

[0080] In an embodiment, a Recursive Convolutional Neural Network (RCNN) or a similar structure may be used to enhance the changes in the captured residual light in subsequent captured images, due to passage of NGT or existence of a secondary condition, for better detection of NGT passage and/or a secondary condition.

[0081] In an embodiment, the first neural network can be further configured to perform such enhancements in a single network structure.

[0082] At step F in Figure 2, the processor module 202 stores and retrieves corresponding data regarding the inspection of NGT intubation and/or detection of a secondary complication in a target subject from the database 210. The data may be used for further analysis or condition matching for action recommendation.

[0083] Figure 3 shows an example embodiment where the illuminator module, using an IR LED as light source, is passed through the subject's throat alongside the NGT, during the intubation process, to illuminate the NGT passage route from within, while an IR camera is capturing one or more digital images from the outside and front of subject's throat. In this example, the NGT is passing through the esophagus and therefore the residual IR light should pass through muscle, blood vessels, and cartilage tissues, and therefore cannot be pickup by the digital camera, and thus the system eventually will decide the NGT has not passed through the airway, and is therefore, has passed through the esophagus (as there are only two possible passages).

[0084] Figure 4 provides another example where the example embodiment has the internal illumination by passing the LED light source alongside the NGT, while the IR camera is capturing one or more digital images. In this figure, the NGT has passed through the subject's airway, and therefore the residual IR light passes only trachea structure which is mostly cartilage with limited blood vessel network and is therefore detectable by the IR camera from outside and in front of the subject's throat.

[0085] Figure 5 shows another example embodiment that two digital capturing devices are pointed at the subject's throat from two viewing angles (front and side views in this example), that can provide two or more digital images that may be used for reconstruction of a three-dimensional model of the subject's throat and/or airway.

[0086] As another example embodiment, Figure 6 shows two examples of illuminator modules that can be passed through or alongside the NGT. The first example embodiment (Figure 6, right) is a sheathed illuminator including an IR LED as the light source, related power cables, and safety cable(s). The second example embodiment (Figure 6, left) is an illuminator module that transfers light from an external IR LED, using an optical fibre, and a reflective surface (e.g. a metallic ball) at the end of the fibre to diffuse the transported light onto the surrounding tissues at the end of the optical fibre. Both of these example embodiments can be passed through the subject's throat inside or alongside the NGT during the intubation process and pulled out after NGT localization and confirmation of correct placement of NGT.

[0087] Figure 7 shows another example embodiment that includes an external illuminator module containing an array of IR LEDs as light source, illuminating the subject's throat from outside and right of the airway, and an IR camera that captures one or more digital images from outside and left of subject's throat. In this example embodiment, the system can detect the disturbances to the residual IR light passing through the airway tissues, if the NGT is passed through the airway.

[0088] The examples described here are of course provided by way of example only and are not intended to be limiting.

[0089] Use of the term "module" herein may be understood to mean a single computing device or a plurality of interconnected computing devices which operate together to perform a particular function. That is, the module may be contained within a single hardware unit or be distributed among several different hardware unit designed for use with other components or modules. For example, a module may be implemented using discrete electronic components, or it can form a portion of an entire electronic circuit such as an Application Specific Integrated Circuit (ASIC). Numerous other possibilities exist. Those skilled in the art will appreciate that the system can also be implemented as a combination of hardware and software modules.

[0090] An exemplary computing device which may be operating as a module is described below with reference to Figure 9.

[0091] Figure 9 shows a schematic diagram of a computer device or computer system 1000 suitable for realizing the processor module 202, the first neural network module 204, the second neural network module 206 and/or the image capturing module 208 and illuminator module 212. The following description of the computing device 1000 is provided by way of example only and is not intended to be limiting.

[0092] As shown in Figure 9, the example computing device 1000 includes a processor 1003 for executing software routines. Although a single processor is shown for the sake of clarity, the computing device 1000 may also include a multi-processor (including graphical processing units) system. The processor 1004 is connected to a communication infrastructure 1006 for communication with other components of the computing device 1000. The communication infrastructure 1006 may include, for example, a communication bus, cross-bar, or network.

[0093] The computing device 1000 further includes a main memory 1008, such as a random-access memory (RAM), and a secondary memory 1010. The secondary memory 1010 may include, for example, a hard drive 1012, which may be a hard disk drive, a solid state drive or a hybrid drive and/or a removable storage drive 1014, which may include a magnetic tape drive, an optical disk drive, a solid state storage drive (such as a USB flash drive, a flash memory device, a solid state drive or a memory card), or the like. The removable storage drive 1014 reads from and/or writes to a removable storage unit 1018 in a well-known manner. The removable storage unit 1018 may include magnetic tape, optical disk, non-volatile memory storage medium, or the like, which is read by and written to by removable storage drive 1014. As will be appreciated by the persons skilled in the relevant art(s), the removable storage unit 1018 includes a computer readable storage medium having stored therein computer executable program code instructions and/or data.

[0094] In an alternative implementation, the secondary memory 1010 may additionally or alternatively include other similar means for allowing computer programs or other instructions to be loaded into the computing device 1000. Such means can include, for example, a removable storage unit 1022 and an interface 1020. Examples of a removable storage unit 1022 and interface 1020 include a program cartridge and cartridge interface (such as the found in video game console devices),

a removable memory chip (such as an EPROM or PROM) and associated socket, a removable solid state storage drive (such as a USB flash drive, a flash memory device, a solid state drive or a memory card), and other removable storage units 1022 and interfaces 1020 which allow software and data to be transferred from the removable storage unit 1022 to the computer system 1000.

[0095] The computing device 1000 also includes at least one communication interface 1024. The communication interface 1024 allows software and data to be transferred between computing device 1000 and external devices via a communication path 1026. In various embodiments, the communication interface 1024 permits data to be transferred between the computing device 1000 and a data communication network, such as a public data or private data communication network. The communication interface 1024 may be used to exchange data between different computing devices 1000 which such computing devices 1000 form part an interconnected computer network. Examples of a communication interface 1024 can include a modem, a network interface (such as an Ethernet card), a communication port (such as a serial, parallel, printer, GPIB, IEEE 1394, RJ45, USB), an antenna with associated circuitry and the like. The communication interface 1024 may be wired or may be wireless. Software and data transferred via the communication interface 1024 are in the form of signals which can be electronic, electromagnetic, optical or other signals capable of being received by communication interface 1024. These signals are provided to the communication interface via the communication path 1026.

[0096] As shown in Figure 9, the computing device 1000 further includes a display interface 1002 which performs operations for rendering images to an associated display 1030 and an audio interface 1032 for performing operations for playing audio content via associated speaker(s) 1034.

[0097] As used herein, the term "computer program product" may refer, in part, to removable storage unit 1018, removable storage unit 1022, a hard disk installed in hard disk drive 1012, or a carrier wave carrying software over communication path 1026 (wireless link or cable) to communication interface 1024. Computer readable storage media refers to any non-transitory tangible storage medium that provides recorded instructions and/or data to the computing device 1000 for execution and/or processing. Examples of such storage media include magnetic tape, CD-ROM, DVD, Blu-rayTM Disc, a hard disk drive, a ROM or integrated circuit, a solid state drive (such as a USB flash drive, a flash memory device, a solid state drive or a memory card), a hybrid drive, a magneto-optical disk, or a computer readable card such as a PCMCIA card and the like, whether or not such devices are internal or external of the computing device 1000. Examples of transitory or non-tangible computer readable transmission media that may also participate in the provision of software, application programs, instructions and/or data to the computing device 1000 include radio or infra-red transmission channels as well as a network connection to another computer or networked device, and the Internet or Intranets including e-mail transmissions and information recorded on Websites and the like.

[0098] The computer programs (also called computer program code) are stored in main memory 1008 and/or secondary memory 1010. Computer programs can also be received via the communication interface 1024. Such computer programs, when executed, enable the computing device 1000 to perform one or more features of embodiments discussed herein. In various embodiments, the computer programs, when executed, enable the processor 1004 to perform features of the above-described embodiments. Accordingly, such computer programs represent controllers of the computer system 1000.

[0099] Software may be stored in a computer program product and loaded into the computing device 1000 using the removable storage drive 1014, the hard disk drive 1012, or the interface 1020. Alternatively, the computer program product may be downloaded to the computer system 1000 over

the communications path 1026. The software, when executed by the processor 1004, causes the computing device 1000 to perform functions of embodiments described herein.

[0100] It is to be understood that the embodiment of Figure 9 is presented merely by way of example. Therefore, in some embodiments one or more features of the computing device 1000 may be omitted. Also, in some embodiments, one or more features of the computing device 1000 may be combined together. Additionally, in some embodiments, one or more features of the computing device 1000 may be split into one or more component parts.

[0101] It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A method for facilitating inspection of nasogastric intubation in a target subject, comprising:

illuminating with a light source at least a portion of the throat;

obtaining one or more digital images of at least a portion of the throat;

extracting a plurality of feature vectors from the one or more digital images;

and

identifying, using a deep neural network, the presence of nasogastric tube in the airway based on the plurality of extracted feature vectors.

2. The method according to claim 1, the method further comprising:

processing the one or more digital images of the images of the throat for segmentation of the body parts and/or background prior to extracting the plurality of feature vectors from the one or more digital images.

3. The method according to claim 2, wherein the step of processing the one or more digital images of the throat for segmentation of the body parts and/or background comprises:

down-sampling the one or more digital images of the throat;

coarse segmentation of the down-sampled one or more digital images;

and refinement of the coarse segmented one or more digital images.

4. The method according to claim 1, wherein two or more digital images of the throat are obtained separately from two or more digital image capturing devices spaced apart from each other, wherein the method further comprises:

constructing a three-dimensional model of the throat and/or airway based on the two or more digital images of the throat; and

processing the three-dimensional model of the wound for segmentation of the body parts and/or background prior to extracting the plurality of feature vectors from the one or more digital images.

5. The method according to claim 4, wherein a second trained deep neural network is used to facilitate construction of the three-dimensional model of the throat and/or airway.

6. The method according to claim 5, wherein one or more digital images of the throat are obtained, wherein the method further comprises:

extracting a plurality of feature vectors from the one or more digital images; and

identifying a secondary complication based on the extracted feature vectors.

7. The method according to claim 7, wherein the secondary complication comprises of at least one of: anomalies in tissues such as inflammation, abscess, ulcer, or cancerous tissues, anomalies in blood vessels such as blockage, and internal bleeding.

8. A system for facilitating inspection of nasogastric intubation in a target subject, comprising:

one or more illuminator modules configured to illuminate at least a portion of the throat or airway using one or more light sources from either within or outside the throat;

one or more image capturing modules configured to obtain one or more digital images of at least a portion of the throat;

a processor module configured to extract a plurality of feature vectors from the one or more digital images; and

a first neural network module configured to implement a first trained deep neural network for identifying presence of nasogastric tube in the airway based on the plurality of extracted feature vectors.

9. The system according to claim 8, wherein the processor module is further configured to process the one or more digital images of the throat for segmentation of body parts and/or background prior to extracting the plurality of feature vectors from the one or more digital images.

10. The system according to claim 9, wherein the processor module is further configured to:

perform down-sampling the one or more digital images of the wound;

perform coarse segmentation of the down-sampled one or more digital images; and

perform refinement of the coarse segmented one or more digital images, for segmentation of the body parts and/or background.

11. The system according to claim 8, further comprising two or more digital image capturing devices spaced apart from each other and configured to separately obtain two or more digital images of the throat, wherein the processor module is further configured to:

construct a three-dimensional model of the throat and/or airway based on the two or more digital images of the throat; and

process the three-dimensional model of the throat for segmentation of the body parts and/or background prior to extracting the plurality of feature vectors from the one or more digital images.

12. The system according to claim 11, further comprising a second neural network module configured to implement a second trained deep neural network to facilitate construction of the three-dimensional model of the throat and/or airway.

13. The system according to claim 11, wherein one or more digital images of the throat are obtained, and the processor module further configured to:

extract a plurality of feature vectors from the one or more digital images; and

identify a secondary complication based on the extracted feature vectors.

14. The system according to claim 13, wherein the secondary complication comprises at least one of: anomalies in tissues such as inflammation, abscess, ulcer, or cancerous tissues, anomalies in blood vessels such as blockage, and internal bleeding.

15. The system according to claim 11, wherein the illuminator module is further configured to:

illuminate at least a portion of the throat with one or more light sources from within or outside the throat;

16. The system according to claim 15, wherein the illuminator module is further configured to comprise of one or more light sources that emit one or more wavelengths including visible, near-IR, IR light, or a similar wavelength.

17. The system according to claim 16, wherein the illuminator module is further configured to: attach, detach, or slide to the side of the nasogastric tube, and into the throat.

18. The system according to claim 17, wherein the illuminator module is further configured to: cover the light source and other related components with a transparent sheath to avoid contact with bodily fluids.

19. The system according to claim 15, wherein the illuminator module is further configured to: transport the light from an external light source, into or alongside the nasogastric tube and into the throat, using optical fibre or similar material.