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# Segmentation of abdominal organs from CT using a multi-level, hierarchical neural network strategy

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ABSTRACT

Precise measurements on abdominal organs are vital prior to the important clinical procedures. Such measurements require accurate segmentation of these organs, which is a very challenging task due to countless anatomical variations and technical difficulties. Although, several features with various classifiers have been designed to overcome these challenges, abdominal organ segmentation via classification is still an emerging field in order to reach desired precision. Recent studies on multiple feature–classifier combinations show that hierarchical systems outperform composite feature–single classifier models. In this study, how hierarchical formations can translate to improved accuracy, when large size feature spaces are involved, is explored for the problem of abdominal organ segmentation. As a result, a semi-automatic, slice-by-slice segmentation method is developed using a novel multi-level and hierarchical neural network (MHNN). MHNN is designed to collect complementary information about organs at each level of the hierarchy via different feature–classifier combinations. Moreover, each level of MHNN receives residual data from the previous level. The residual data is constructed to preserve zero false positive error until the last level of the hierarchy, where only most challenging samples remain. The algorithm mimics analysis behaviour of a radiologist by using the slice-by-slice iteration, which is supported with adjacent slice similarity features. This enables adaptive determination of system parameters and turns into the advantage of online training, which is done in parallel to the segmentation process. Proposed design can perform robust and accurate segmentation of abdominal organs as validated by using diverse data sets with various challenges.



## 1. Introduction

Analysis (i.e. volume, size) and visualization of the abdominal organs (i.e. liver, spleen, right and left kidneys), tissues (i.e. lesions, tumors) and other structures in the abdomen (i.e. prostate [21], abdominal part of the aorta) are necessary and important steps prior to several clinical procedures including diagnosis, therapy and surgery. Besides other modalities in use for analysing abdominal region (such as MR [17] and PET [54]), computed tomography-angiography (CTA) [27] is a widely used radiographic technique. It has several advantages on both clinical (i.e. allowing minimally invasive interventions) and technical (i.e. low radiation exposure, less acquisition time) sides [42]. For producing effective and clear visualizations of abdominal organs and for obtaining precise measurements, segmentation is the most important step of the pipeline. However, two main issues, which are imposed by variations in human anatomy and image characteristics make the segmentation process extremely challenging.

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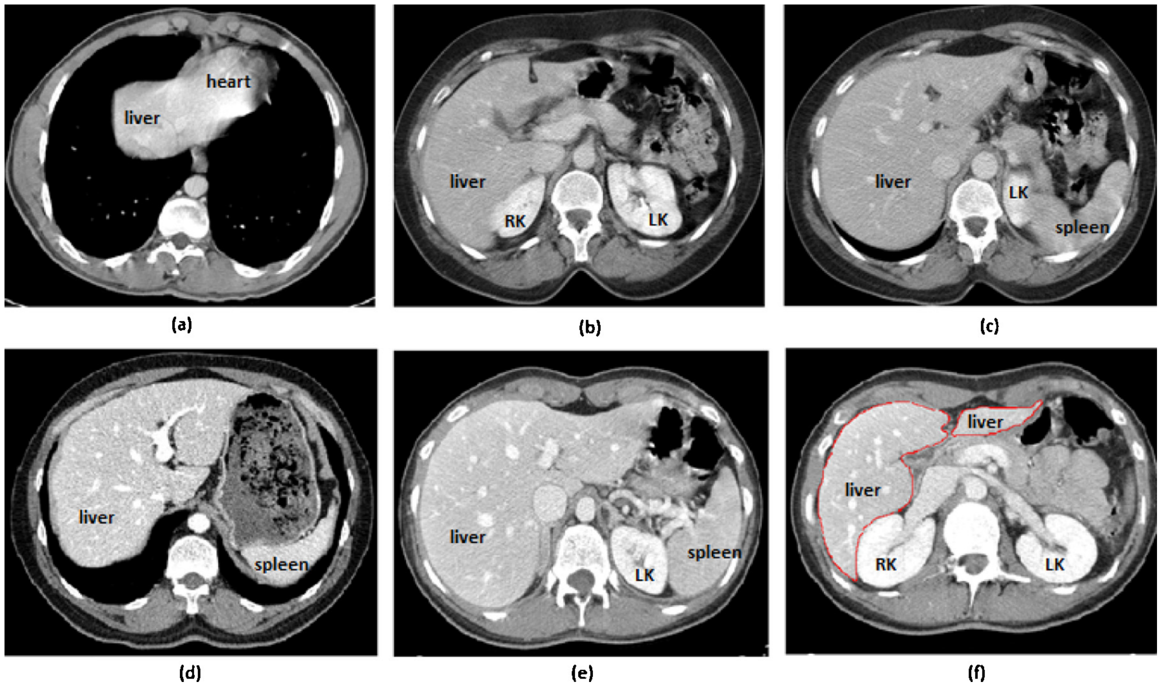


**Fig. 1 – Examples of abdominal CTA slices showing diversity and variations (a) very low contrast difference and unclear boundary between heart and liver; (b) unclear boundary due to partial volume effects between the right kidney and liver; (c) unclear boundary due to partial volume effects between left kidney and spleen; (d) contrast enhanced vascular tissues inside liver parenchyma; (e) relatively less enhanced vessels compared to (d); and (f) multi-part liver, contrast enhanced kidney tissues. Abbreviations: LK, left kidney; RK, right kidney.**

### 1.1. *Anatomical variations*

Unlike some relatively fixed organs in the body (i.e. brain), the human anatomy in abdominal region shows great diversity, which causes various changes in shape, size, orientation and even position of abdominal organs. This leads to countless variations even in normal anatomy and prevents the use of basic models. It is also not rare (e.g. 15% percent for liver Soler et al. [48]) that patients have atypical organs (i.e. very unusual shape, texture, size, orientation or position). This diversity of variations decreases the performance of several techniques including [5], model (i.e. generalized cylinders as geometric primitives [3], spatial [29], population-based geometric [50], stochastic [28] models) and atlas-based [56,41] analysis and limits their use to a subset of all cases.

### 1.2. *Technical difficulties*

In CT imaging, rendering soft tissues have severe limitations due to their representation in a very narrow band of overlapping Hounsfield (HU) value ranges [19]. This drawback limits the performance of many techniques that are based on intensity (i.e. dynamical thresholding [31], gray level [55]), morphology [22] or their combination [2]). Moreover, the organs and tissues can get very different values than their expected HU ranges in: (i) different patient data sets due to different modality settings or (ii) different slices of the same data set due to injection of contrast media.

Partial volume effects, patient movement, reconstruction artifacts and other external factors may cause blurred edges and low contrast in the acquired images. Moreover, in CTA, the parenchyma of abdominal organs become inhomogeneous due to the enhanced anatomical structures (i.e. vessels, tumors, lesions) (Fig. 1b–f), which become substructures that have different textures. This prohibits the benefits of texture based techniques [32], even when they are used in volumetric sense [35]. Thus, different processing techniques are required for texture based approaches [14]. These inhomogeneities and blurring also limit emerging useful techniques that depend on the homogeneity of gray levels and/or gradients in an image (i.e. level sets [43], region growing [52], fast marching [6], active contours [26]).

There are also several studies that combine different methods to develop specific algorithms for abdominal organ segmentation [7,39,38,47,37]. These algorithms can be collected under the heading of rule-based techniques since they incorporate some knowledge about anatomy and/or image characteristics. Among those, especially for the liver, clinically promising results are reported in [23], which compares successful algorithms using very detailed analysis. However, more research is still necessary until the abdominal organ segmentation problem can be considered largely solved, since each limitation during segmentation can significantly reduce the correct measurement of quantitative parameters (i.e. volume of an organ) [18].

Neural network (NN) based approaches are useful alternatives in handling abdominal image segmentation. However, NN based segmentation procedures should be designed carefully in order to show enough and reliable performance. There are mainly two challenges that should be