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Automat. Comput. Appl. Math.
Volume 28 (2020), Number 1

COMPUTER SCIENCE

Segmentation of the Hepatocellular Carcinoma Structures within Computed Tomography Images using Convolutional Neural Networks

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***Abstract*—Hepatocellular carcinoma (HCC), is the most common type of malignant liver tumor diagnosed in adults. Due to the difficulty of diagnosing those types of tumors, and due to the fact that the standard of diagnosing such tumors is through needle biopsy, more research in less intrusive methods of diagnosis is required. For this purpose, we study the effect of recent advancements in semantic segmentation convolutional neural networks(CNN) in order to identify HCC regions from contrast enhanced computed tomography (CT) images. For this purpose, we compare multiple CNN architectures specific for the segmentation task, using appropriate metrics, such as the Intersection over Union (IoU) and the Dice coefficient. The finally obtained performance was above 70% for IoU, respectively above 80% for the Dice coefficient.**

***Keywords*—Deep learning, semantic segmentation, hepatocellular carcinoma (HCC), convolutional neural networks (CNN), computed tomography (CT) images.**

I. Introduction

Hepatocellular carcinoma (HCC) represents the most common malignant liver tumor, present in 70% of the liver cancer cases, the sixth most frequently met cancer, respectively the second cause of cancer-related death worldwide. It results from cirrhosis, after a liver parenchyma restructuring stage, at the end of which dysplastic nodules, future HCC, result. In incipient phase, HCC appears as a small structure, having 3-5 cm in size. Further, it increases in dimensions, becoming heterogeneous and usually hyperechogenic in advanced evolution phases. Nowadays, the golden standard for HCC diagnosis is still the needle biopsy, but this is a dangerous, invasive procedure, as it could result into infections, respectively in a spread of the tumor through the human body [1].

In our research, we design and develop computerized, non-invasive methods for HCC characterization, recognition and segmentation. These methods are aimed for being employed both in computer aided and automatic diagnosis, respectively in computer aided surgery. In this work, we perform the automatic segmentation of HCC within contrast enhanced CT images, the final objectives being to elaborate a 3D model of the tumor and of its anatomic context, using images collected before the surgical intervention, respectively to detect and localize the tumor during the surgical intervention, in order to inject a chemotherapeutic, destructive agent into it, through a specialized medical robot. Thus, in the current research, we compare the performances of multiple CNN architectures, appropriate for performing HCC segmentation within contrast enhanced CT images.

Concerning the previously existing similar methods, various approaches regarding the segmentation of the tumor structures within medical images can be taken into account, involving both traditional methods (enhanced clustering techniques, active contour models) [2], [3] as well as deep learning methods [4], in particular Convolutional Neural Networks (CNN) [5]. However, no relevant approach exists for performing a systematic comparison of the CNN architectures that lead to the best performance concerning the HCC segmentation within CT images. We perform this task in our current research. We also compare the achieved performance with that resulted when employing a conventional segmentation method, based on an enhanced Fuzzy-C-Means Clustering algorithm [6].

The paper is organized in the following way: section II presents related work for the topic of tumor segmentation from medical data, section III describes the CNN architectures trained in our study, section IV presents the experiments and interprets the result and section V concludes the paper.

II. Related Work

According to the conventional approach, texture analysis methods in conjunction with classical segmentation methods were employed for tumor segmentation within various types of medical images. Thus, in the article [3], the authors use a combination between Gabor filters, Support Vector Machines (SVM) and 3D deformable models in order to perform prostate segmentation within 3D ultrasound transrectal images. A method for brain tumor segmentation within magnetic resonance images (MRI), based on textural parameters and supervised classifiers, is described in [7]. Here, the authors determine first order textural features, such as the grey level arithmetic mean and variance, energy, entropy, histogram skewness and kurtosis, as well as second order statistics based on the Grey Levels Cooccurrence Matrix (GLCM). All these features are provided at the entrances of a metaclassifier based on ensembles of classifiers. Another fully automatized method, described in [2], was employed for womb tumor segmentation within ultrasound images. During the first phase, taking into account textural features and clustering

Computerized system for modeling the HCC tumors and their anatomical context based on CT images

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***Abstract*—The Hepatocellular Carcinoma (HCC) is the most frequent malignant liver tumor, appearing in 70% of the liver cancer cases. The treatment of these tumors involves the HCC surgical resection, but in advanced evolution phases, this treatment is inapplicable. In these situations, minimum invasive surgical treatments for tumor reduction are considered appropriate. We develop a computerized system for assisting this surgical treatment, which generates the 3D anatomic model of HCC tumors, based on Computed Tomography (CT) images. In this work, we focus on the segmentation methods which target the HCC tumor and on the 3D reconstruction methodology which uses the automatic segmented images. For HCC segmentation, we experimented multiple CNN architectures, using 286 CT images of 42 patients. Our computerized system was validated, by comparing the results of the 3D reconstruction employing the outcome of the CNN based HCC segmentation, with those employing the manual delineations of HCC performed by radiologists.**

***Keywords*—Hepatocellular Carcinoma (HCC), 3D anatomic model, semantic segmentation, 3D reconstruction, computed tomography (CT) images.**

I. Introduction

The Hepatocellular Carcinoma (HCC) is the most frequent malignant liver tumor, appearing in 70% of the liver cancer cases, as well as one of the most leading causes of cancer related death over the world. It evolves from cirrhosis after a liver parenchyma restructuring phase, at the end of which dysplastic nodules, future HCC, result. Usually, the treatment of these tumors involves the HCC surgical resection, but in advanced evolution phases, this surgical treatment is inapplicable, as the tumor is very large and might also intersect important blood vessels. In these situations, specific, minimum invasive surgical treatments for tumor reduction, as, for example, the injection of a harmful agent, are considered appropriate. We develop a computerized system for assisting these types of surgical treatments, assuming the generation of the 3D model of the HCC tumors and of their anatomical context, based on Computed Tomography (CT) images. In order to build the HCC 3D anatomic model, we firstly perform the automatic segmentation of the anatomic elements through specific methods, then the result of the segmentation process is provided to the 3D reconstruction module. Similar computerized systems, aiming to assist surgical treatments of HCC, exist nowadays, some representative approaches being described in [1], [2], [3], [4]. However, none of these approaches assesses and employs advanced segmentation and 3D reconstruction methods in order to generate a highly accurate 3D anatomic model of HCC. This research work focuses on the corresponding HCC segmentation methods and on the 3D reconstruction process involving the segmented images. For HCC segmentation, we experimented multiple CNN based techniques, such as ERFNet and UNet, assessed through the Intersction over union (IoU) metric, respectively through the DICE coefficient. These networks were experimented on 286 CT images belonging to 42 patients, trained on axial plane slices represented in Hounsfield units. The 3D reconstruction was performed using the segmented images, by employing specific methods of the VTK library [5], postprocessing operations being also performed, in order to obtain a smooth HCC surface within the model. Our computerized system was validated on six representative patients by comparing the results of the 3D reconstruction employing the outcome of the CNN based HCC segmentation, respectively the manual delineations of the HCC contours performed by the radiologists, the final accuracy being estimated around 60%. This system will communicate with a medical robot, by providing to it, during surgery, the 3D anatomic model of HCC and the 2D slices which correspond to various positions and orientations of the ultrasound transducer, assisting, in this manner, the accurate application of the tumor reduction treatment assuming the injection of a harmful substance in the right place.

II. Related Work

Regarding the computerized systems that assist the HCC specific surgical treatments various approaches exist in the nowadays literature, the most relevant being presented below. Thus, in [1], a computerized system that generates, before surgery, a 3D model of the liver and tumor anatomical model is described. The Myrian-XP-Live application was employed in this context, for performing automatic information extraction, regarding the liver or tumor parenchyma, as well as the important arteries and veins, finally resulting 3D reconstructed images of the liver and liver volume estimates, besided the location and size of the tumor, the objective being the destruction of the HCC tumor through Radiofrequency

Deep Learning Based Masses Segmentation Method in Mammograms

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***Abstract*—The current paper presents a method for automatic segmentation of potentially malignant abnormalities in 2D mammographic images based on pixel level classification using convolutional neural networks (CNN). Experiments were performed for masses segmentation by training U-Net models on the CBIS-DDSM dataset using original algorithms for data preprocessing in order to obtain an augmented and balanced training dataset and post-processing for semiautomatic evaluation. In terms of masses detection rates, a FPPI (False Positive Per Image) rate of 3.65 and a sensitivity (True Positive Rate – TPR) of 0.77 were obtained on the whole test data set, which are closed to the ones reported in the literature, proving that the proposed method has the potential to be integrated in mammography CAD applications for assisting screening programs in which the a main goal is a high true positive rate and a small false negative rate.**

Keywords – 2D mamograms; preprocessing; segmentation; automatic masses detection; deep learning; convolutional neural networks

I. INTRODUCTION

Breast cancer is one of the main diseases that affect women's life and is amongst the main causes of death related to cancer, if not discovered in the early stages. The pathology has an asymptomatic early phase that can be detected through mammography. The WHO (World Health Organization) concluded that 23% of cancers are breast cancer and 14% lead to death [1].

The main hardship in the detection of potentially malignant abnormalities (especially masses and micro-calcifications) is due to the acquisition process of the 2D mammograms (digitalized or film), meaning that a 3D structure is projected on a 2D plan, which leads to increased noise due to tissue overlapping, especially for dense glandular tissues. Therefore, 10% to 15% of cancers are invisible on mammograms, as the dense glandular tissue might hide 30%-50% of cancers [2].

The double interpretation (independent and simultaneous visualization of the mammograms by two radiologists) has been enforced as a standard in most of the screening programs, thus decreasing false-negatives detection [3]. This technique requires more time and additional expenses, as a digitized mammogram usually averages above 10 megapixels.

As an alternative to double blind interpretation, computer tools such as CADe (Computer- Aided Detection) or CADx (Computer Aided Diagnostics) can be used to provide a second opinion when mammograms are interpreted by a single radiologist. Amongst the limitations of these methods we mention: the high detection rate of false positives for CADe [4] or their limited-acceptance in clinical practice for CADx [5]. Most of the 2D mammography CAD Tools (3D mammography [6] is not the subject of the current paper due to limited access to such a technology) are able to detect abnormalities (as masses and calcification) based on traditional pattern recognition and machine learning algorithms as [7], [8], and [9] and are focused on reducing the false negative detection rate. Only a few tools such as ProFound AI, and SecondLook from iCAD [10] claim to use state of the art approaches based on Artificial Intelligence (AI) and Deep Learning (DL).

Recently, deep learning methods based on convolutional neural networks (CNN) have proven superior performance, including the medical imaging field. Instead of manually selected mathematical or heuristic features, these algorithms can automatically generate discriminative features at different levels of abstraction.

A hybrid mass classification method that combines feature extraction with a CNN network and a traditional SVM type classification method is presented in [11]. As training dataset for the neural network, the INbreast[12] data set was used, containing both mammograms digitized from films with a color depth of 8 bits/pixel and digital mammograms (16 bits/pixel). In [13] and [14] a method for mass detection is presented in several stages: in the first phase hypotheses are generated through a hybrid approach in which deep convolutional networks cascade with random decision tree type classifiers, followed by a segmentation stage based on deep learning models and a refinement stage using "level-set" methods. The authors report a true positive detection rate TPR = 0.96 at 1.2 FPPI (false positive per image) on the INbreast data set and TPR = 0.75 at 4.8 FPPI on the DDSM-BCRP data set [15].

A mass segmentation method that combines FCN (Fully Convolutional Networks) with the CRF method (Conditional Random Fields) and the contradictory learning technique (adversarial learning) is presented in [16]. The authors present comparative results obtained on the INbreast and DDSM-BCRP datasets between the various combinations of the three techniques used and other methods from the CNN-based literature. A method for mass detection is presented using a RetinaNet type deep convolutional network in [17]. The authors also use the transfer learning technique by which the weights of the network are pre-trained on one dataset and used in training and testing on another dataset. The authors also present a comparative analysis in terms of the FPR vs. FPPI metric of their own method in the context of the transfer learning technique on the INbreast dataset and on GURO dataset (their own data set), as well as compared with other segmentation methods based on deep networks or traditional methods on different datasets (INbreast, DDSM). In [18], a method for masses and micro-calcifications segmentation using dedicated neural network architectures (AlexNet, VGGNet, GoogleNet, ResNet) is presented. For each type of

On visual odometry estimation using linear methods - a mathematical framework

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***Abstract*— Visual odometry is a well established computer vision technique used for estimating the motion of a video sensor from the apparent motion of the pixels in the image plane. When using stereo cameras, it is possible to recover the 6 degrees of freedom motion (rotation and translation). While the majority of the methods are relying on minimizing non-linear cost functions, it is also possible to formulate the optimization problem as a system of linear equations like we have originally shown in [9] for stereo cameras and in [17] for mono cameras combined with other depth perception sensors like LiDAR. This paper explains the mathematical details of the method previously proposed in [9] for small magnitude frame-to-frame motions and proposes a generalization capable of handling higher rotation angles too. In order to achieve the latter we use the initially estimated rotation parameters for adjusting the features in the $(\mathbf{u}, \mathbf{v}, \mathbf{d})$ space, followed by a second estimation of the motion parameters starting from the adjusted state.**

Keywords—visual odometry, rotation matrix, linear visual odometry, computer vision, camera ego-motion

I. INTRODUCTION

Motion estimation (known as odometry) from video cameras is an attractive technique given the relatively small costs of video sensors and given the high precision estimations that can be achieved from high resolution cameras. Roughly speaking, a camera having a horizontal (or vertical) opening angle θ can lead to a measurement precision of the relative rotation between consecutive frames in the order of magnitude smaller than $\theta/10N$, where N is the horizontal (or vertical) camera resolution in pixels. We assume sub-pixel precision of the optical flow vectors from which the motion is estimated. For these reasons, every smart device (e.g. drones [15], smart helmets [8], automated cars [18]) that is using camera sensors can take advantage of the ego-motion estimation. Computing resources used for such video signal processing methods are an important limitation that such smart devices come with, while real-time performance on embedded hardware requires careful design of dedicated solutions [19][20].

This work focuses on describing the mathematical framework that we previously introduced in [9] and proposes a generalization of the method by adding the capability to handle large rotations while still keeping the linear nature of the problem formulation and solution estimation.

II. RELATED WORK

In general visual odometry methods are relying on using the essential matrix constraint formulation [25][26] or non-linear optimization methods for two [24] or multiple [21][22][23][27] consecutive frames. The use of linear methods for decreasing the computation load was previously explored for visual odometry in [9] and has its roots in early computer vision theoretical reports like the one in [30]. Linearizing the motion parameters based on the so called small angles assumption is also exploited in [29] for rigid 3D body motion estimation from stereo images.

The current work generalizes and builds on top of our previous work from [9].

III. METHOD DESCRIPTION

A. Notations and basics

We consider a 3D point in front of a calibrated camera having the coordinates:

$$P = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad (1)$$

in a system with its origin in the camera projection center, with X axis pointing laterally and being aligned with the u axis in the image plane (columns), Y axis pointing down and being aligned with the v axis in the image plane (rows) and Z axis pointing forward (Figure 1).

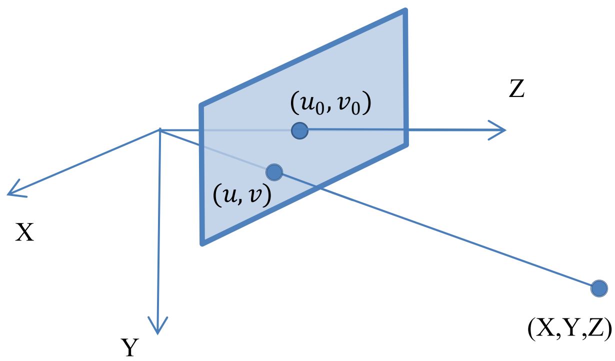

Figure 1. The camera coordinate system and the projection of a 3D point (X, Y, Z) in the image plane

Towards the Next-Gen Technologies for Internet: The Internet of Things

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***Abstract*—This article represents a study that was conducted in the domain of new technologies that have been developed during the last two decades for Internet and some of its major services, such as the World Wide Web. Those technologies are known under the name of 'Internet of Things'.We will show here theoretical considerations, present and analyze the architecture with its stack of technologies, new computing paradigms, protocols and service standards that have been created to support their operability which are characterized by certain constraints, the most important is that they are battery-powered devices and communication must consume as least power as possible. We will make comparisons with the old, traditional technologies for Internet and state what are the advantages and improvements they bring, how they are expected to change our lives in better, what are the social and economic impacts. The results of our researches are presented in tabular form, with tables containing various data we gathered from the resources in literature, which we analyzed, combined and processed them in order to provide the reader with a rich set of information about the domain. Then were made a series of discussions around these results in order to show their meanings, explain their repercussions on economical growth and life quality in terms of the growing in number of devices connected to IoT and money spent for automating the world (cities, homes, clothes, etc).**

***Keywords*—Internet of Things, Smart Things, battery-enabled devices, low-power communication, networks of connected objects**

I. Introduction

The Internet of Things (abr. IoT), also known by the names of Internet of Everything, or Embedded Internet, is a network of physical nodes, called 'things' bundled with electronic devices, sensors, connectivity, software that enables them to exchange data with the operators, production or other devices based on the infrastructure of International Union of Telecommunications [12],[20]. Internet of Things allows objects to be sensed and controlled remotely over the network infrastructure, enabling a better integration into the real world, having as main goal the improvement of the efficiency, accuracy, speed and, in a final extent, quality of life. The definition, as found on the Wikipedia site says that: "the ever-growing network of physical objects that feature an IP address for Internet connectivity and the communication that occurs between them and other Internet-enabled devices" [20].

It can be said that IoT extends Internet connectivity beyond traditional devices to a diverse range of devices and things that utilize embedded technology to communicate and interact with the external environment via Internet. Fig.1 shows a high-level conceptual model and fig.2 presents its architecture with the component layers.

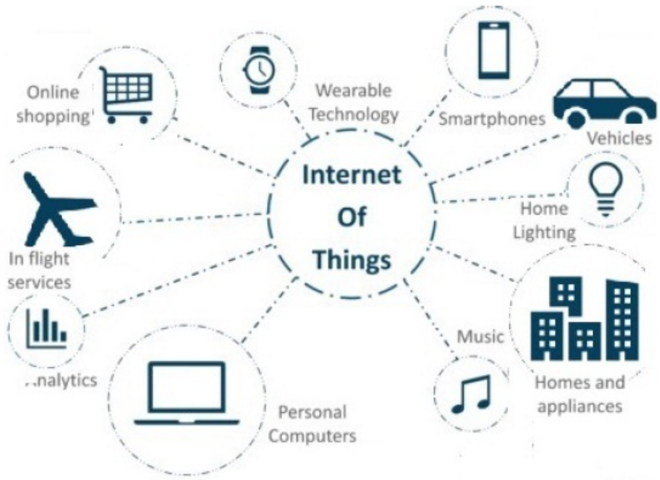

Fig. 1. Conceptual Scheme of IoT

Even though the term is relatively new, the idea existed in fragmented bits since few decades ago, especially in pervasive (ubiquitous) computing [6],[21]. The landmark papers that stand at the origins of these concepts are the seminal article of Mark Weiser from 1991 Scientific American magazine [19], that introduced the fundamental concepts behind pervasive computing, and a presentation of Kevin Ashton from Procter&Gamble in 1999 in the context of RFID supply chains in which he coined the actual term [1].

II. Architecture

The research literature proposed different architectures for IoT. The most basic type of architecture is the one with three layers (fig.2A), that was introduced at the early days of researches in the domain. Its layers are:

- Perception layer: is constituted of sensors having the role of 'sensing' the environment and collecting information
- Network layer: is responsible for providing the connectivity of things, for the transmission and processing of data provided by sensors
- Application layer: has the role to deliver application specific services, like ones from smart homes, smart grids, smart cities

Fig.2B represents a more fine-grained architectural model constituted of 5 layers. The Perception and Application are the same as in previous model. We will present next the others three:

How Well Does Computational Linguistics in Achieving Its Task?

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***Abstract*—In this work we propose to make a discussion and analysis regarding what is considered by scientists the most advanced intellectual faculty of humans, which is that of language (or communication), either spoken or written, and will show how has been managed to be emulated with the aid of technologies from Computer Science domain created in the last decades. Will be presented and analyzed the different categories of knowledge required to engage in even the most simple form of dialogue consisted of 2 sentences, a task which is seen as the most basic for us, humans at first glance. This domain belongs to the greater Artificial Intelligence one and in the last decades had been created specialized branches that deal with solving the problems of implementing language into machines, such are Computational Linguistics, Natural Language Processing, Speech Recognition and Synthesis etc. We will show what technologies have been created for this purpose, each for which class of knowledge required in exhibiting good language behavior. The article will end with a discussion around the main application areas of this science and present the major technologies and systems created so far that are capable of language and communication behavior, such are those from the operating systems of our smart computing devices, like PCs, smartphones and tablets, intelligent houses etc. We will end with a section of conclusions where we'll summarize the best things that we achieved in this article and state the future directions of our research, such is to show and understand how the language processes happen at us, humans at the psychological and also neurological level.**

***Keywords*—Language capacity, Computational Linguistics, Artificial Language Production and Understanding, Machine Learning technologies**

I. INTRODUCTION

Language is a cognitive capability that evolves throughout the man's lifetime [21]. Human language capacity is considered by scholars of the domain as the most important faculty that differentiates us from even the most advanced other primates. It's emergence and evolution at us, humans, is a problem to which not even now, after centuries of thought, a straight answer has been found. One of the first researches into this field are considered those of the scientists Charles Darwin and Noam Chomsky from the XIV-th century. These made the claim that a genetic mutation occurred at an individual in the interval of a hundred thousands years ago that installed the language faculty. [15],[25].

Today two major theories exists regarding the birth of this unique capacity [2]. The first one is called the "native theory", whose beliefs are that we are born with this faculty and that complex syntactic structures, like recursion, are hard coded inside our brain, resembling thus to Chomsky's hypothesis. The second one is called the "cognitive" (mentalist) theory, which states that we are not born with this capability but acquire and develop language structures throughout our life and from social interactions. This theory is sustained also by Psychology and gained a lot of ground over the native one during the last decades, especially after the development of Computer Science technologies, with more focus on the AI's. Also the behavioral school of Psychology sustains the idea that language is a behavior that is modeled by a conditioned answer, so it's learned [23]. These capabilities are thought to be beyond the reaching possibilities of even the most evolved other primates.

The field of science that deals with statistical modeling of the human natural language from a computational perspective as well as the study of computing techniques for the linguistic problems is Computational Linguistics [16]. This is a sub-domain of what is currently a full-fledge science, which is that of Artificial Intelligence (AI), but was seen as to have existed before it. It's considered to have been occurred in the 1950s following the efforts from United States of using computers for automatic translation of texts from the russian scientific journals to English. It was initially thought that computers will make this king of translations in the same manner that they do with arithmetic computations, i.e. much more easier and accurate than humans. Unfortunately this is not the case with language computation, and when automatic translation failed in making accurate translations, automatic processing of the natural language was recognized as a task far more difficult than was initially considered, and, to quote what Wagner says in a recent article from 2016: *Natural Language Processing in no Free Lunch* [19]. Computational and quantitative models had been used in the past with goal of reconstructing the early language patterns and grouping the modern languages into families of languages. The early methods included Lexicostatistics, Glutochronology, and proved to be premature and inaccurate. Recent approaches that borrow concepts from Biology, such as genes association, proved to be some more sophisticated analysis tools and yield more accurate results. [18]

Computational Linguistics arose as a new scientific field having as main goal to create algorithms and methods for the intelligent processing of the information of language. In order to translate between two languages it was found that is necessary to have knowledge of their grammars, such as morphological (grammar of the words' shapes), or syntax (structure of propositions and phrases). In order to understand the syntax must be understood also the semantics and lexicon (vocabulary) and even some concepts of pragmatics (the meaning of words in contexts). So, what initially started as