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Medical imaging data analysis using 3D deep learning models towards improving the individual treatment plans

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A R T I C L E I N F O

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A B S T R A C T

This work is a part of a research project aiming at delivering the next generation active medical phantom, Dose-3D, with high spatial granulation for quasi-real time measurement of the volumetric radiotherapeutic dose deposited during photon therapy. The preliminary results, discussed here, pertain to the intelligent medical data augmentation using Generative Adversarial Networks (GANs) technique implemented inside MONAI framework. However, in the scope of the project, we perform a broad search for the most efficient and advanced Deep Learning (DL) models to create tools for 3D Computed Tomography (CT) images segmentation and cancer diagnosis improvement that will be an integral part of the custom designed software platform for processing data collected with Dose-3D phantom. Apart from the innovative detection system the software itself may prove to be disruptive in the context of the currently available tools by offering open-source high quality toolkit for wide use in everyday clinical applications.

1. Introduction

Because the medical field has a strong relation with intelligent systems, many medical applications are supported by DL-based techniques [1]. Due to the fact, that the preparation of the 3D radiotherapeutic medical plan (i.e., therapeutic dose to be delivered) for cancer-diagnosed patients is a challenging task the Dose-3D project [2, 3] aims at designing a custom software platform, PyDose3D, that will incorporate, among others, various techniques of intelligent medical data processing and analysis to support and verify it. The goal is to prepare a reliable fully-automatic intelligent pipeline comprising the data augmentation, image segmentation and diagnosis improvement tools exploiting the most advanced ML models. Such software suite would be able to perform efficient training of a model able to distinguish between the affected area and surrounding healthy organs inside the patient's body on basis of provided 3D Computed Tomography (CT) scan images. The project has been divided into two stages. First, we want to provide a reliable model for image segmentation featuring the performance matching or exceeding the commercial tools (such as NVIDIA CLARA). Since the data samples provided by hospitals are small, such procedure must include data augmentation step based on a generative model. Next, we want to search for a model that will use the segmented images to improve the diagnosis process. In this paper we present a preliminary results related to the image segmentation studies performed using a Generative Adversarial Networks (GANs) model.

2. Medical data analysis

Segmentation. Individual treatment plans are currently being prepared using, almost inclusively, tools based on analytical methods, which may generate significant uncertainties. One of the core ideas of the Dose-3D software project is to use a high-quality GEANT4 simulation and particle transport engine and ML techniques for therapeutic dose

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estimation. The key point is to deliver the proper patient geometry for both Dose-3D phantom configuration and to the simulator. Most often it is in the form of a 3D CT scan of the human body with precise delineation of the pathological changes. This process of extracting the desired object from a medical image is called segmentation and most commonly this procedure is being performed manually by medical specialists. The manual segmentation done by a few different persons can however vary significantly and thus produce additional uncertainties. Thanks to the current stage of ML techniques development supported by powerful massively parallel frameworks it may be possible that the automatic segmentation can, in some cases, surpass human capabilities. Technically, 3D automatic segmentation is the process of assigning a label to every voxel in 3D image such that voxels with the same label define the volume of a specific part of the human body. The training of high-quality segmentation model depends critically on the size of the training sample, which in turn, can be enriched by properly trained generative model.

Data preprocessing and augmentation. Working with standard medical data format (Digital Imaging and Communications in Medicine—DICOM) requires deep understanding of its structure, including complicated metadata content, and designing a dedicated pre-processing pipeline, concerning mask creation, format conversion, adjusting resolution, scaling intensity, visualization as well as data augmentation, which stands for artificially increase the size of available data sample by generating new instances using the real patient images. So far no generic generative models exist able to augment any type of cancer. Instead each organ requires that dedicated training is performed using the best model chosen in a grid search studies. On top of that the medical data are sensitive which means that an involved anonymization procedure must be performed. Thus, any training that aims at obtaining a high-quality prediction must be enhanced by the augmentation procedure.

3. Technologies

Working in three dimensions requires high computational power and GPU's support in the process of ML models training. This is the reason for using dedicated platforms such as NVIDIA Clara, that apart from increasing the training performance up to 50× with domain-specific GPU optimization also provides state of the art pre-trained deep learning models and more modern powerful techniques. MONAI engine, which is also integrated with the latest Clara platform, is the open-source Python framework for deep learning healthcare imaging that provides a set of tools for medical data transformations.

4. Preliminary results and plans for the future

The very first deep learning model based on Generative Adversarial Networks (GANs) architecture (see Fig. 1) has been build and tested for 3D medical data augmentation purposes. The dataset "CT Images in COVID-19" from public database [4] including 650 CT images of the chest of 632 patients in the early stages of COVID-19 infection has been used as the training data. The construction of the GANs was based on the basic architecture of the Generator (G) and Discriminator (D) models implemented in MONAI. Both networks (G and D) consists of sequences of convolutional layers, transpose convolutional layers and residual units. Moreover, a layer with a sigmoidal activation function has been added to the Generator. The standard GAN loss function, also known as the min–max loss, has been used. The training was carried out with using 20 samples of training data. The number of training epochs was set as 400.

Despite using the basic architecture, standard loss function and small sample of data the results look promising (see Fig. 2). Plans for the near future include work on improving the network structure, fine-tuning its hyper-parameters and efficient training with usage of GPU acceleration.

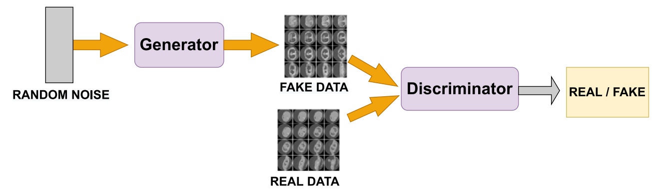

Fig. 1. The figure presents the basic mechanism of GANs.

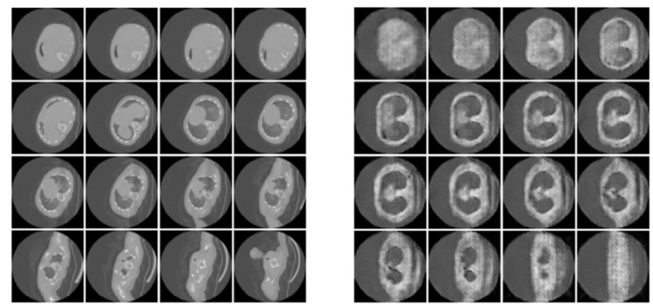

Fig. 2. The figure presents original data sample from public database [4] (left) and data generated by generative Generative Adversarial Networks (GANs) model built and trained using MONAI.

5. Summary

The intelligent medical data analysis, which includes data augmentation, automatic segmentation as well as data pre- and postprocessing can improve the quality of detection of target volume voxels and thus guarantee a better optimization of the treatment plan. The Dose-3D project has a potential to revolutionize radiotherapy thanks to its innovative detection system as well as open-source high quality software.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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