Caring is Sharing – Exploiting the Value in Data for Health and Innovation
M. Hägglund et al. (Eds.)

doi:10.3233/SHTI230345

Towards a Digital Twin in Human Brain: Brain Tumor Detection Using K-Means

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Abstract. Digital Twins come to revolutionize the ongoing procedures of healthcare industry, with their ability to stimulate and predict patients' diagnosis and treatment. In this paper a K-means based brain tumor detection algorithm and its 3D modelling design, both derived from MRI scans, are presented towards to the creation of the digital twin.

Keywords. Digital Twin, Brain Tumor, Clustering, K-means

1. Introduction

At the dawn of the 4th industrial revolution, Digital Twin (DT) comes to be at the center of study. Digital Twin technology is the third trending technology for 2020[1]. A Digital Twin (DT) is a virtual replica of a physical object or a system and reflects its properties. A Digital Twin environment provides a rapid analysis and real-time decisions made through accurate analytics, running multiple processes at once. This is made possible with the acquisition of real time data, via technologies such as sensors. 3D Scanning and Machine Learning techniques are applied on the collected data in order to be used on the replica[2]. Nowadays, DTs have an impact on many different fields. Some of them are industry, manufacture, smart cities and healthcare. More specifically, in healthcare, the digital twin technology comes to revolutionize the ongoing procedures of patients' treatment and prescriptions. The digital twins are facilitated with the continuously increased volume of the available data from the Internet of Things (IoT) environment and advanced data analysis, all of which aim at a more personal examination of each patient, known as precision medicine. The most common use of a digital twin in healthcare is to replicate a certain body organ in order to monitor it. The most replicated one is the human heart, but a challenging one that has started to be studied is the human brain[3]. Another medial case where Digital Twins prove themselves useful is in the maintenance of the devices used, such as an MRI scanner[13]. Brain tumors are a mass of growing cells in the brain. They assort in benign, the non-cancerous ones, and malignant tumors[6]. They have high mortality rate, which can be seen from the fact that 35.6% of people diagnosed with brain tumor live five years after the tumor detection[9].

2. Related Work

Image Segmentation is the technique to partition the digital image in separate groups. All of the segments in a group have similar pixel features with each other[8]. Mustaqeem A et al. proposed an algorithm which uses different filters to denoise the gray level images. They used watershed and threshold segmentation to segment the image on its different parts. The separation of the tumor from the rest of the MRI was achieved using morphological operators [4]. Masood M et al. used Mask RCNN to classify either tumorous or non tumorous images following a median filter noise removal preprocessing [5]. SVM classification and histogram based segmentation was implemented by Chinnu A. in MRI brain images after noise removal and applying a skull stripping extracted the useful features to feed the classifier [6]. Hossam MM et al. used K- Means with component labelling to cluster the 2D brain slices. Next they rendered the object by using some of its features, they visualized in 3D the final outcome [7].

As it was mentioned the DT in healthcare are used to replicate a certain organ. Pajaziti E et al. created a Virtual Reality (VR) system of human heart from six different patients. The region of interest from each patient was chosen manually and the 3D model was created. It aimed to create an educational VR model of the human heart[14]. Capellini K et al. proposed a novel semi-automatic framework to prepare the right anterior mini-thoracotomy surgery from the 3D model of the aorta and the anterior rib cage (aRC). They used region growing segmentation algorithm to create the aorta model from CT images. For the visualization of the aRC they traced the first five ribs and the sternum in axial and sagittal views. These parts were transformed in polylines and were joined together to create the second part of the 3D model[15].Kardampiki E et al. proposed a framework that combines computational fluid dynamics alongside 3D model of the aorta in order to create a DT pipeline that evaluates the parameters of Modified Blalock Taussig Shunt (MBTS). The ascending/descending aorta sections, aortic arch, epiaortic vessels, the pulmonary branch and the valve plane were segmented so the model was created. Based on that the MBTS part was recognized and with the fluid equations that were created the parameters of the surgery were evaluated [16]. Poletti G et al. created coronary artery DTs of different patients who undergo stent implantation surgery. They used 2D characteristics from different views to combine the information table of the 3D model. Then with the data derived from the OCT scans and the table they constructed the 3D model [17].

3. Methods

3.1. Proposed Framework

The proposed framework is a data driven scenario [12]. The model is constantly fed with updated data that concern the patient. The actual MRI scans of the subject were used in order to create and monitor the patient's brain replica. This is followed by a tremendous amount of data taken from its medical history and real time data from sensors such as mobile EEG technologies etc. The EEG recordings of the patient are used in order to collect useful data, along with the ones provided from the IoT environment, aiming at strengthening the decision making capacity of the twin. Based on that the implementation of a brain tumor detection algorithm is a first step towards the decision making capability of the system.

3.2. Tumor Detection Methodology

The implementation of brain tumor detecting algorithm is based on brightness contrast analysis in MRI scans. It is meant that the tumor has a different, usually more intense, brightness level. This is where a clustering technique was required. K-means is the simplest clustering method that is based on the concept of minimizing the squared distance from the cluster center [7]. The process that was followed is described as a colorized clustering. The input is the 3D MRI image itself where the third dimension is the RGB combination of each pixel. Every cluster is created after the implementation of K-means representing a unique, same-value combination of RGB components. The optimal number of clusters is decided in advance based on the knee rule fro clustering each one of the scans. The Within cluster Sum of Squares or Sum of Squared Errors (SSE) metric shows the euclidean distance sum of all the cluster elements from the cluster centers.

$$SSE = \sum_{n=1}^{cluster\_elements} dist^2(n, cluster\_center) \tag{1}$$

Cluster centers are not a Cartesian combination of points but they are a list containing the RGB components of the cluster color, which defines the RGB combination of the whole cluster. From the clustered image was selected the class which had the highest, value wise, color combination. After the isolation of the pixels a circular mask, with dynamic radius is created. The initial radius value and the center pixels' combination of the mask are specified. The mask checks which pixels within the radius have the same color values as the central one and computes their area within the mask. This process is implemented for each one of the isolated pixels. If the area is over a threshold value then it is considered to be the tumor. Due to the fact that the data set consists of many diverse MRI images the radius adapts itself in any given subject so if the procedure is unable to detect the tumor the radius changes to a smaller value and the masking check restarts.

3.3. 3D Modeling

The right branch of the Figure 1 shows the process to 3D model. The whole design is accomplished with the open source computer-aided design (CAD) software 3D Slicer, using its built-in modules and some extensions provided from the software itself. An automated procedure is aimed to create a 3D model for each subject, on condition that the scans are appropriate.

4. Results

4.1. Data Acquisition

To evaluate the performance of the methodology described previously we used different MRI images taken from different MRI scanners and different conditions. Our data set consisted of 247 MRI images obtained from 11 different Radiopaedia cases[10] and

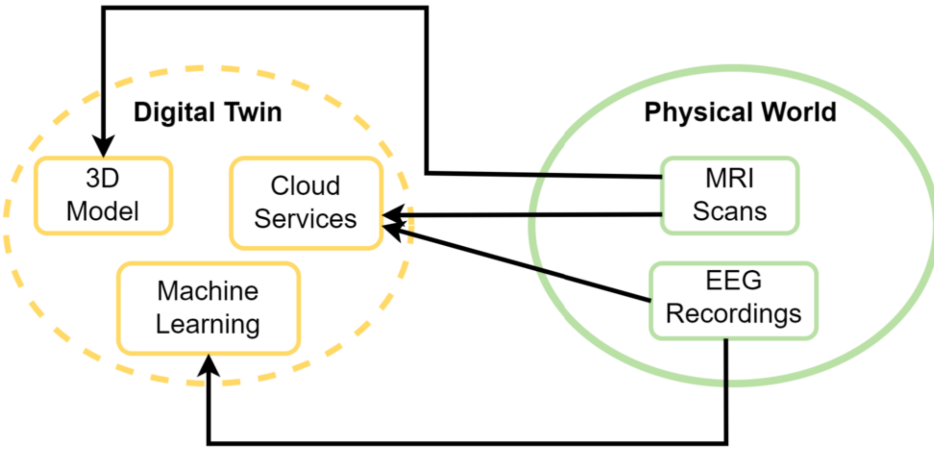

Figure 1. MRI scans processing towards the brain 3D Model and the tumor detection

Brain MRI Images for Brain Tumor Detection by Kaggle[11]. The 59.91% of them referred to patients who suffered from brain tumor and 40.09% referred to healthy patients. The current image format is JPG.

4.2. Experimental Results

The tumor detection algorithm was applied on all 248 scans with different radii varying from 30 to 100. In the non tumorous ones the radius was limited between 30 and 75 and it was observed that the greater the value of the radius is the greater the accuracy score was. The accuracy is defined as the percentage of the images that the algorithm did not find any tumor to the total number of images.

$$Accuracy = \frac{Number\_of\_non\_Tumorous\_Images}{Total\_Number\_of\_Images} \tag{2}$$

This process was made in order to make sure that the algorithm is capable of identifying MRI images of healthy patients from them with tumors. So based on Eq. 2 the accuracy was varying from 0.85% to 0.96% (Mean: 0.92, std: 0.04), which for sure is not realistic due to the limited number of healthy patients' samples that we possessed. As it is shown from the first two steps of Figure 2 it is easily seen that the tumor has been successfully located. Then the 3D model is created by the combination of tumor and brain part visualizations.

5. Future Work

Our future work extends in generalizing the algorithm so it does not only identify tumors as the brightest object of the image but in all cases and remove outliers. In order to achieve that the process will be tested on NIFTI images. Another aspect that will be investigated is the relation of the EEG when brain tumors are present, aiming on more secure decision by the twin. Finally to achieve the ultimate goal of the brain 3D model an attempt of creating the tumor 3D directly after its detection will be implemented.

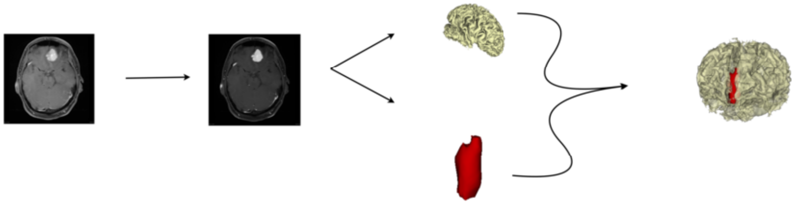

Figure 2. The implementation result. Starting from an MRI, the tumor is detected and then the 3D model of brain and the tumor is constructed .

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