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Automated detection of parenchymal changes of ischemic stroke in non-contrast computer tomography: A fuzzy approach

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ABSTRACT

The detection of ischemic changes is a primary task in the interpretation of brain Computer Tomography (CT) of patients suffering from neurological disorders. Although CT can easily show these lesions, their interpretation may be difficult when the lesion is not easily recognizable. The gold standard for the detection of acute stroke is highly variable and depends on the experience of physicians. This research proposes a new method of automatic detection of parenchymal changes of ischemic stroke in Non-Contrast CT. The method identifies non-pathological cases (94 cases, 40 training, 54 test) based on the analysis of cerebral symmetry. Parenchymal changes in cases with abnormalities (20 cases) are detected by means of a contralateral analysis of brain regions. In order to facilitate the evaluation of abnormal regions, non-pathological tissues in Hounsfield Units were characterized using fuzzy logic techniques. Cases of non-pathological and stroke patients were used to discard/confirm abnormality with a sensitivity (TPR) of 91% and specificity (SPC) of 100%. Abnormal regions were evaluated and the presence of parenchymal changes was detected with a TPR of 96% and SPC of 100%. The presence of parenchymal changes of ischemic stroke was detected by the identification of tissues using fuzzy logic techniques. Because of abnormal regions are identified, the expert can prioritize the examination to a previously delimited region, decreasing the diagnostic time. The identification of tissues allows a better visualization of the region to be evaluated, helping to discard or confirm a stroke.

1. Introduction

Cerebrovascular diseases according to the World Health Organization are the third leading cause of death and the leading cause of disability in industrialized countries. The term "stroke" is used to describe the clinical phenomenon which consists of a sudden onset of neurological symptoms due to a cerebrovascular disorder. In contrast, cerebral infarction describes a lethal ischemic phenomenon at tissue level that corresponds to 85% of the cases of stroke [1]. A stroke can be classified into two major groups depending on its nature: hemorrhagic and ischemic [2]. The average duration of non-lacunar stroke evolution is 10 h. Ischemia can cause functional neurological damage or may present as a cerebral infarction, which causes irreversible neuronal structural damage. Each minute, 1.9 million neurons, 14 billion synapses, and 12 km (7.5 miles) of myelinated fibers are destroyed [3].

Because of its wide availability, low cost, fast execution and proven efficacy, Non-contrast Cerebral Computer Tomography (NCCT) is the first choice for neuroradiology examination of all patients presenting an acute focal neurological deficit [4]. CT helps to differentiate the type of stroke and to discard other diseases that may cause a vascular process similar to a stroke such as tumors, bleeding, metastasis, etc. [5–10]. It also reports the dimensions of an ischemic lesion and indirect signs such as cortical grooves asymmetry, structural displacements, density increase in the middle cerebral artery in the basal tract, or attenuation coefficients of the brain's parenchyma [11–14]. Initial changes in CT may be present within the first 3 h after the onset of the stroke and this

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may, or may not, influence the selection of patients for thrombolytic therapy [15,16]. More than half of protocol violations are due to a failure to recognize the first signs of infarction on initial CT [17]. There is considerable discordance, even among the more experienced physicians, about the recognition and quantification of such early CT changes [18], since it is subject to observer variability due to many factors [6]. The human eye is able to differentiate a limited number of 20 Gy tones, which means that the contrast resolution is limited to 4 Hounsfield Units (HU). The window width of 80 HU gives a remarkable maximum change of 1–2 Gy levels within the first 4 h of ischemia [19]. Diffuse changes can hardly be distinguished in noisy areas due to low contrast brightness, bone artifacts and non-optimal scanning.

Usually the detection of early changes of ischemic stroke in CT is performed manually by a radiologist and sometimes with the use of simple software tools such as contrast modification. There are various CADe (Computer Assisted Detection) schemes that integrate mathematical models to help identify abnormalities that physicians may overlook and, therefore, the software improves the efficiency of disease detection. CADe systems for automatic detection of early ischemic changes still need further research and improvement [20]. The implementation of an algorithm based on computer vision techniques, as part of the development of a CADe, would allow the expert radiologist (and not expert) to perform a detailed search on specific areas of the brain where the algorithm has detected the possible presence of a stroke. This would accelerate the beginning of the treatment that should be up to 7.3 h after symptom onset [21]. By obtaining a more timely diagnosis and its consequent treatment, a disability and even death of the patient can be avoided, thus reducing morbidity and mortality.

Few contributions have been made in the literature of CADe based on computer vision techniques for ischemic changes detection. In Ref. [22] brain abnormality was inferred from the histogram comparison of hemispheres. The method was only tested in chronic infarction cases where the stroke is easily detectable. Other methods also use histogram-based comparison, starting from a segmented region of interest (ROI) [13]. Because early density changes can hardly be seen, it can be difficult to decide where to establish the ROI. Depending on where the ROI is established, the stroke can be overlooked. The comparison of symmetric ROIs does not necessarily mean a strict comparison of the corresponding structures due to partial volume effects, cerebrospinal fluid or white matter may affect the attenuation coefficients of a region.

In Ref. [23], the data was interpolated to a single volume: a skull-stripping algorithm was used, then normalized using an atlas, and segmented into anatomical regions. The voxel densities in the lentiform nucleus and insula were compared to the contralateral side using statistical analysis for the detection of hypodensity. A method of post-processing improvement with comparison of distributions of attenuation coefficients was proposed in [24]. It was based on the analysis of voxels using normalization, segmentation and differentiation of the original CT and the resulting filtered image.

Other well-known methods of local contrast enhancement to visualize hidden structures in medical imaging are based on the adaptive equalization of the histogram [25,26]. A local window is considered for each individual pixel, and then a new intensity value is calculated based on the local histogram. The method does not change the overall appearance of the image, which is important for clinical reading since such variations usually distract the attention of radiologists. However, shadow-like artifacts appeared in fairly homogeneous regions and, in some cases, thin structures were attenuated. These disadvantages were reduced when the adaptive equalization of the histogram was performed [27,28].

This wavelet-based algorithm [29] was proposed for simultaneous automatic visualization of the full range of dynamic contrast of CT. Interpretation times were significantly reduced. Post-processing in the wavelet domain was less susceptible to artifacts and perturbations, unlike the exact representation of adaptive histogram equalization techniques. The diagnostic accuracy, however, was insufficient compared to conventional window viewing. Wavelets were also used to detect strokes [19]. The perception of early changes was improved by eliminating noise and enhancing local contrast. The method improved the subtlest signs of hypodensity, which were often invisible in the standard CT scan. Data processing became more effective through the initial segmentation of brain tissue and the extraction of regions susceptible to density changes. The sensitivity of stroke diagnosis increased to 56.3% compared with 12.5% of the standard CT scan.

Semiautomatic algorithms have also been proposed. In Ref. [30] the radiologist defines de ROI by selecting an initial seed point (a voxel) that belongs to the structure of interest. It uses intensity-based region growth algorithms that exclude ventricles and hemorrhages. The damages are evaluated according to the seed selected by the radiologist; however, the technique is too slow since it takes 2 h per study.

Recently, there have been diverse contributions to the literature of methods that seek to automate the ASPECTS protocol. In Ref. [31] an automated ASPECTS scoring method was developed as an alternative to manual ASPECTS score. Based on the brain density shift between contralateral brain areas, the method quantifies subtle early ischemic changes. The method matched with manual consensus scoring in 73% of the cases without bias or outliers, in contrast with individual observers. A new software, the e-ASPECTS, was proposed for the automatic detection of acute ischemic stroke. The method segments the regions using texture information and an atlas. It generates a score and marks the regions that contain the damage. It offers a direct score based on the image in order to indicate or discard thrombolytic therapy. The e-ASPECTS has been evaluated in Refs. [32,33] concluding that it is non-inferior to the ASPECTS results scored by three neuroradiologists on NCCT.

Because the identification of early ischemic changes in acute strokes is still very subjective, we must continue to focus on the development of diagnostic tools that improve the perception of subtle changes and that allow stroke-specialists to determine an early diagnosis with greater precision.

Brain tissue segmentation (BTS) plays a key role in the study of various abnormalities, brain development and evaluation of the progress of treatment [34]. Cerebrospinal fluid (CSF), white matter (WM) and gray matter (GM) are the basic tissue types in BTS. Subsections of the image with specific characteristics are labeled with the aim of achieving homogeneous partitions representing CSF, WM and GM. Several segmentation techniques have been proposed in the literature for BTS, mostly designed for their use in magnetic resonance imaging (MRI) [35–37]. In CT the contributions have been limited to the segmentation of pathologies and brain parenchyma excluding the separation of tissues [38–40].

The inherent difficulty in segmenting and quantifying the various brain tissues has increased the use of soft computing techniques in BTS. Fuzzy logic as a part of soft computing has the potential to combine human heuristics in computer-aided decision making, it opens the door to construction of better models of reality and involves exploitation of a tolerance for imprecision [41]. Fuzzy logic has been applied in all disciplines of medicine in some form of classification, detection, segmentation and control, and recently its applicability in neurosciences, especially in brain tissue segmentation, is also increasing [34,42,43].

This research proposes a new computer vision method that identifies changes in parenchymal density in Non-Contrast Computer Tomography for the detection of early stages of ischemic stroke. Based on the analysis of cerebral symmetry, the method identifies non-pathological and cases with abnormalities. The iden-