Artur Przelaskowski[1]
Jerzy Walecki[2]
Katarzyna Szerewicz[2]
Paweł Bargieł[1]
[1]Politechnika Warszawska, Instytut Radiolelektroniki, Nowowiejska 15/19, Warszawa, arturp@ire.pw.edu.pl
[2] Zakład Diagnostyki Obrazowej CSK MSWiA, ul. Wołoska 137, Warszawa

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ACUTE STROKE DETECTION IN UNENHANCED CT EXAMS: PERCEPTION ENHANCEMENT BY MULTI-SCALE APPROACH*

***Abstract*: Nonenhanced CT exams were used to detect acute stroke by hypodense area notification. Two methods of perception improvement were tested: review window settings and local contrast enhancement in multi-scale domain. Wavelet-like transform and signal distribution was optimized. Modified display of CT images was verified in initial tests with several data sets and participation of 3 radiologists. Improved conditions of stroke diagnosis were notified. Further clinical experiments are necessary to optimize and make the enhancement methods more reliable.**

1. INTRODUCTION

Nonenhanced CT is often the first radiologic examination in the setting of suspected stroke. It provides a relatively quick way of excluding conditions that may mimic ischemic stroke and may require a different treatment approach. The advent of thrombolytic therapy for acute stroke treatment makes early detection of areas of hypoattenuating ischemic parenchyma exceedingly important [1,2,3].

The earliest signs of ischemic infarction are loss of sulcal delineation, obscuration of the lentiform nucleus, loss of insular ribbon and/or hyperdense middle cerebral artery. Afterwards, it becomes possible to detect a hypodense area of infarction. Initially, the low density region is poorly defined, becoming more sharply delineated beyond 24 hours. A few studies have reported findings of infarction as early as 6 hours [4].

Our research is based on the hypothesis that it is possible to improve the ability to detect the changes of acute ischemic brain parenchyma on nonenhanced CT scans. Moreover, in animal models of middle cerebral arterial (MCA) stroke, the decrease in CT attenuation in ischemic tissue due to cytotoxic edema is less than 8 HU (Hounsfield unit) at 4 hours after infarction [3].

The detection of acute ischemic brain parenchyma with nonenhanced CT scanning is facilitated by soft-copy visual review at a diagnostic workstation by using variable, standard and nonstandard window width and center level settings. Well-fitted visualization parameters, chosen to strengthen this small difference between normal and hypodense areas, could increase the conspicuity of hypoattenuating tissue.

Linear intensity windowing techniques are the simplest and most commonly used method to improve the conditions of diagnosis. Proper selection of review window parameters can improve the detection and delineation of hypodense area. Such hypothesis was verified and partially confirmed by the considerations and results presented in [2,3,5]. We studied the objectivity of the widow setting criteria.

More complex but more fruitful way of perception improvement is adaptive histogram equalization in multi-scale data domain applied for CT exams [4,6]. We optimized multi-scale method with local contrast enhancement to increase a visibility of poorly circumscribed hypodense regions. Different transforms and adaptive histogram-based modification algorithms were analyzed and tested, and the most effective method was concluded.

2. METHODS

Two ways of CT-based acute stroke detection was considered: well-fitted window width and center level selection and the modification of multi-scale distribution of transform coefficients.

2.1. Window settings

Center level and width of window were experimentally fitted to test data in order to improve hypodense area delineation. Edge extraction and maximally increased local contrast was the criterion of optimization. Moreover, histogram equalization of image data was used for single image display without windowing resulting in decreased time of diagnosis. An automatic single-window display can help focus the radiologist's attention on all tissues on an image without necessitating a change of window parameters.

2.2. Multi-scale perception enhancement

The goal of contrast enhancement was to determine an optimal conversion function relating original gray level and the displayed intensity such that contrast between adjacent areas of different density in an image was maximally outlined.

Multiresolution decomposition offer additional capability of modeling, modifying or amplifying image

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features selectively based on spatially distributed properties over different scales and subbands. Lower frequency parts offer distinguished information about poor textures and mean value estimates in regions. A correlation of high frequency information across scales portrays even very weak edges.

The enhancement process adjusted multi-scale coefficients of interests at some particular spatial-frequency location by modeling a distribution of their magnitudes in a context of surrounding data. Nonlinear amplifying of small coefficients in selected subbands was applied. Next the image was reconstructed with modified coefficients.

Monitoring of hypodense regions over different scales (inter- and intra-scales, subbands) and possibility of their enhancement by increasing distinction from background was the subject of our analysis.

Decomposition schemes including many wavelet filter banks, undecimated wavelets, contourlets, number of scales, data grid conversions (hexagonal 2D kernels) were fitted for perceptual hypodense region extraction.

3. RESULTS

The result of our research was improved region of interest extraction in several test cases**.** 11 test sets consisted of acute stroke image (initial stage) and later image with clearly visible hypodense area (developmental stage). Initial experimental optimization of the display according to subjective criteria was performed.

Our experiments indicated the ways of acute stroke detection improvement. Reliable clinical tests are necessary to allow recommendation of the enhanced display methods as a replacement for conventional window display. The examples of improved stroke perception are presented in fig. 1 and 2.

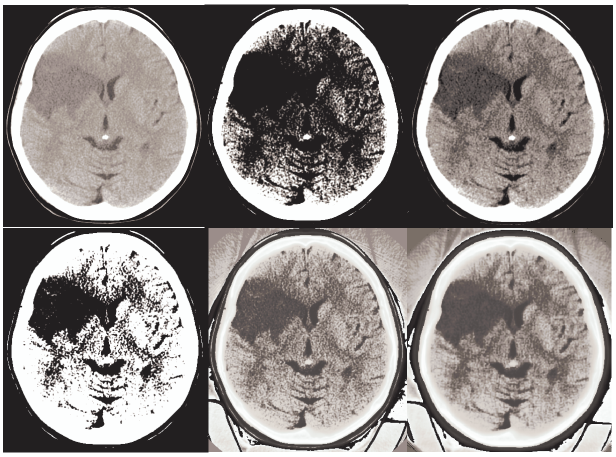

Fig 1. Enhancement of stroke visualization (left-right, top-bottom): standard 80/20 and optimized 8/32 [3] windows, ***2 proposed stroke display: 40/30 and narrow 3/25 windows****, single-window display of histogram equalization of image and undecimated wavelet data.*

4. DISCUSSION AND CONCLUSIONS

It is difficult to select one optimal multiresolution decomposition and contrast enhancement method for all CT brain exams. Biorthogonal 9/7 filter bank based on smooth splines and amplification of small magnitudes in middle and high frequency subbands according to formula: $n \cdot c \cdot |c|^{p-1}$ with normalization n and parameter p gave the best results of hypodense area extraction for the majority of test cases. Formal optimization of multi-scale transformation that maximizes perception improvement by modification of coefficients distribution doesn't agree with knowledge of experts in several cases. Nevertheless, image modeling in multi-scale domain seems to be useful and more efficient than image-space based perception improvement methods.

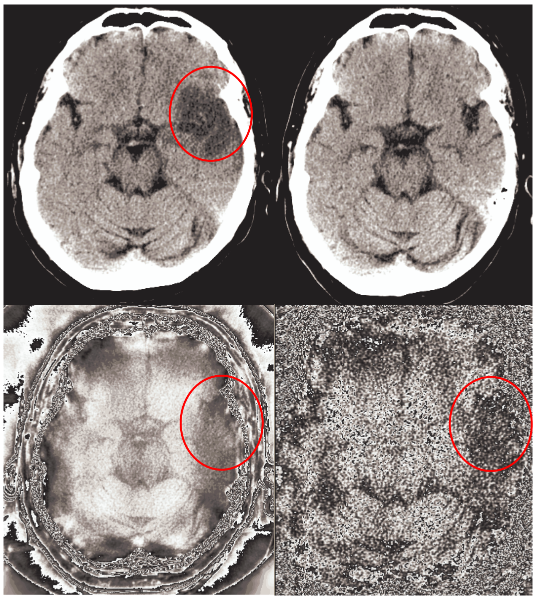

Fig 2. Enhancement of acute stroke detection (left-right, top-bottom): developmental stage of stroke, initial stage in 40/30 window (no signs) followed by its enhanced multi-scale displays with visible hypodense area.

Objective verification of review window settings is difficult because of case and radiologist dependence. Common expertise in the clinical domain and image processing ideas is required to refine the techniques to match the properties of the image information of interest.

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