Image processing of medical diagnostic neurosonographical images in MATLAB

Jiří Blahuta, Tomáš Soukup, Petr Čermák

***Abstract*—**This paper presents a processing of medical ultrasound images with MATLAB. This processing is useful to potential diagnosis of Parkinson´s disease in brain-stem area. Furthermore introduces DICOM standard for medical imaging and modern 3D/4D scanning for high level and accuracy of diagnoses that is higher than traditionally 2D scanning.

***Keywords*—**ultrasound,4D imaging,DICOM,neural,MATLAB

I. Introduction to modern imaging

In this section we introduce standard DICOM and modern 3D and 4D medical imaging for precise level of diagnoses. It is usable not only in neurosonography, but generally in modern medical ultrasound viewing.

Nowadays, US devices are fully compatible with DICOM standard and produce very sensitive images with high resolution. Furthermore, US image are not only 2D, but 3D or 4D. It is described in next chapter. 3D/4D imaging is the next step to more precise diagnoses not only in neurology. US, against other techniques, has no damaging influence to human body. Also US is appropriate method for scanning in neurology, brain is small, very sensitive and soft tissue. In this paper we will show how to work with US images of brain stem with detection of defects in substantia nigra which is a part of stem.

A. DICOM standard

For medical imaging, storing and transferring data from various modalities has been developed a standard DICOM[1] (*Digital Imaging and Communications in Medicine*). It is international standard for medical informatics. Nowadays is used version DICOM 3.0 and was developed and described in 1993. It is not format only for imaging, but it is global standard for using of medical data from modalities such as CT, US, PET and another RDG modalities.

Each image in DICOM format has a unique identity which is described by SOP (Service-Object Pair) class, which is unique number structure. Example of SOP number is

1.2.840.10008.5.1.4.1.1.2 (CT Image Storage).

DICOM images do not content image only, but is connected with metadata about modality, exposition, date, patient and more information. Modern sonographical devices certainly work with DICOM standard. Data are interconnected between hospitals and doctors. DICOM image usually has DCM or DIC extension as file and contents:

- slices of image with adjustable contrast
- metadata about patient, modality, SOP identity, device and more.

The primary benefits of DICOM against converted image are original lossless quality with metadata and a lot of slices (layers) in one file. You can easily change the contrast for ROI imaging. DICOM standard is managed by NEMA association (*National Electrical Manufacturers Association*).

Software that be able to work with DICOM files, for example *DicomWorks*[2], *Aeskulap Viewer*[3] (freeware) and commercial software *Amira*[4], *Photoshop Extended* (CS4 or newer) and certainly *MATLAB* (with Image Processing Toolbox).[5]

B. 4D ultrasound imaging in neurology

Modern ultrasonographical devices (not only) in neurology work in DICOM standard and offers 3D/4D mode of scanning. We have not only 2-dimensional image, but we can work with third, coronal axis for 3D reconstruction. 4D imaging is a form of 3D extended by time shift. In 4D we can see complete 3D reconstruction and phase for model reconstruction. 4D mode is more precise and objective than 2D image.

Modern ultrasound probes work in 3D/4D mode and are multifrequential for scanning different tissues. Images from US modality are appropriate for neurosonography because US is sensitive for soft tissues such as brain parts. An example of 4D ultrasound scan is showed on the following figure.[6]

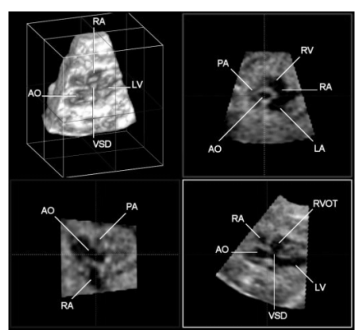

Fig. 1 An example of 4D ultrasound scan

In 3D mode case, image elements are in 3D topology and are described as voxels (volume elements). In this 3D grid

[1] http://www.rsna.org/Technology/DICOM/index.cfm

[2] http://dicom.online.fr

[3] http://aeskulap.nongnu.org/

[4] http://www.amira.com/amira.html

[5] http://www.mathworks.com/help/toolbox/images/f0-18117.html

[6] http://www.medphys.ucl.ac.uk/mgi/fetalhrt/sj-tof2d-3db.jpg

The project was supported by grant “Artificial Intelligence in Robotics and Medical Informatics SGS/6/2011”.

topology, voxels are arranged regularly. Impulses must be in 3D layout. Probes during exposition on pacient are rotated or bended. 4D imaging adds time for reconstruction, it is extended level of 3D imaging. Simply, 4D ultrasound takes 3D ultrasound images (3D sonograms) and adds the element of time to the process. If we select ROI in 4D image, area will be highlighted in “information cube” which is based on 3D viewing. 3D/4D volume rendering display some new diagnostical information on ROI against traditional 2D viewing despite volume rendering is more challenging for data postprocessing. We can illustrate the development of ultrasound imaging by the following diagram.

2D +coronal ⇒ **3D** +time ⇒ **4D**

Multiplanar reconstruction is one of used 3D form. It is an upgrade from 2D to 3D imaging, which is in neurosonography very well usable. Generally, 4D imaging is actual phenomenon in modern ultrasound imaging.[7]

C. Working with DICOM images in MATLAB

MATLAB environment with Image Processing Toolbox naturally supports a DICOM files. We can read and save DICOM files and extract metadata from it. MATLAB reads a DICOM files as 4-D structure (signed 16-bit data) and for viewing we need to use autoscaling function. Detailed information about working with DICOM in MATLAB are available in MATLAB Help and web documentation[8].

For example we adduce an example of metadata from neurosonographical image which can be extracted from DICOM file by dicominfo function. List was shortened, shows only example of data.

Filename	'c:/sebmri/seber.dcm'
FileModDate	'25-I-2011 11:06:52'
Format	'DICOM'
FormatVersion	3
BitDepth	8
ColorType	'truecolor'
MediaStorageSOPClassUID	'1.2.840.10008.5.1.4.1.1.3.1'
SOPClassUID	'1.2.840.10008.5.1.4.1.1.3.1'
Modality	'US'
Manufacturer	'GE Vingmed Ultrasound'
StationName	'VIVID7-012711'

Table 1 – Extracted data from DICOM file

II. Parkinson´s disease and substantia nigra

Some information about role of substantia nigra (SN) in brain stem and Parkinson´s disease diagnosis and features.

A. Substantia nigra in brain stem

Substantia nigra (SN; in English “black substance”) is a brain structure located in the mesencephalon (midbrain) that plays an important role in reward, addiction, and movement. SN produces a important dopamine for correct function of CNS (Central nervous system). The CNS is one of the two major divisions of the nervous system. SN is our ROI for processing and searching pathological defects to Parkinson ´s disease diagnosis. The first criterion for diagnosis may be the area of SN, risk threshold is 0.19 cm^2. SN is very important part of midbrain and is well recognizable by ultrasound as all brain. Ultrasound imagining in neurology is also important for detection another diagnoses such as encephalitis, meningitis, congenital hydrocephalus and so on. The following figure shows the position of SN in brain.[9] We can see that SN is a small part, but very important. Detailed information about substantia nigra and echogenicity are available in [15].

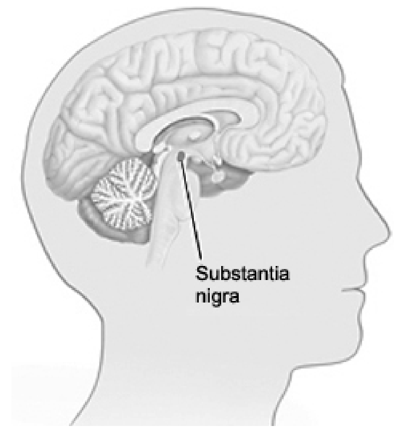

Fig. 2 Position of SN in human brain

B. Parkinson´s disease

Parkinson's disease (PD) is caused by the death of dopaminergic neurons. It is a degenerative disease of basal ganglias inside the brain. PD has been described by James Parkinson in 19th century. The main symptoms of PD include muscle rigidity, tremors and changes in speech and gait and more.[10]

III. The goal of our processing

Despite DICOM is a standard for medical imaging as we described in previous part, for our processing we will use only 2D images. We will use intensity JPEG ultrasound images (grayscale) which were converted from original DICOM format. In this case, image processing of 3D volume data has a high time and memory complexity.

We work with a set of JPEG images. MATLAB is a great tool for image processing with Image Processing Toolbox. Generally, all processing has three critical steps:

- image cropping to position with SN (window)
- specify ROI of SN in stem position
- searching of pathological defects in SN to PD

All processing is realized with MATLAB, which is appropriate for solving. Initially, the following image shows one of our images with highlighted window with brain stem

[7] actual updated information are available on http://www.4dultrasound.net/
[8] http://www.mathworks.com/help/toolbox/images/f13-29508.html
[9] http://www.mountnittany.org/assets/images/krames/134407.jpg
[10] http://www.mdvu.org/library/disease/pd/

which contents SN with image measure and intensity scale.

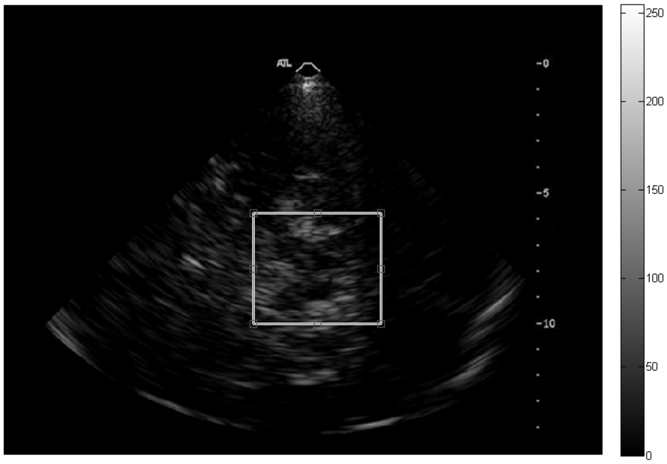

Fig. 3 Window with brain stem area position

We know that position of brain stem with SN is approximately in the same position, we can select a window to this position with imcrop function. This fact is verified by neurologist and we saw sonographical atlas with coronal and axial slices. In this window we will search ROI and defects inside.

A. Image pre-processing

At the first step for every processing is suitable pre-processing for successful application. We got a collection of US images with standard resolution 768×576 pixels in JPEG format with DPI=72. DPI will be determining value to calculating of defects area to diagnosis. Full resolution is large and contents redundant information such as black areas. We need a minimal size of images with ROI retention. Thus, the first step is cropping of images to window with stem area. It is the first step in algorithm. Also, all images have been converted from RGB mode to intensity grayscale by weighted sum of RGB channels:

$$H = 0{,}299\times R + 0{,}587\times G + 0{,}114\times B. \quad (1)$$

Thus, each pixel in matrix has intensity value $H\in\langle 0; 255\rangle$.

We considered about influence of a *speckle noise* that is typical for sonographical data. Ultrasound images are very sensitive to dynamic speckle noise. The speckle noise arises from different tissues and actual position of ultrasound probe. The main problem for reduction is that speckle is not static noise but dynamic in image. If we have these small images then influence is not very considerable despite speckle noise should be reduced. Generally a noise we can describe as redundant information to signal by the following formula:

$$im[I] = u[I]\cdot n[I] \quad (2)$$

This is an example of multiplicative noise such as speckle. Image im*[I]* contents useful information *u[I]* multiplicated by noise part *n[I]*. If we do not reduce speckle noise, some small areas may be evaluated as defects. Speckle noise is evaluated by the following formula.

$$F(g) = \frac{g^{\infty-1}}{(\infty-1)!\,a^{\infty}} e^{-\frac{g}{a}}, \quad (3)$$

where *F(g)* is the intensity level in image.

IV. Practical application

This chapter is fundamental, contents practical application and results which has been created in MATLAB. We explained theoretical background about US, SN, PD and pre-processing and now we will show the results.

We use a binary masks (thresholding by Otsu´s algorithm), morphological operations, boundaries selecting and neural network simulation. MATLAB allows realizing all processing. The following figure shows an example of ROI SN with highlighted potential defects.

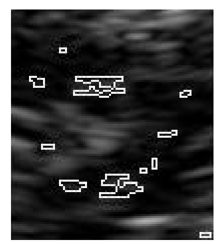

Fig. 4 Recognized defects by morphological operations

In this example are highlighted a defects that are potential to PD diagnose. To boundaries has been used bwperim function after morphology on binary mask. Binary masks are basic for this processing. We must optimize this application to better recognition and doctor can be able to select defects interactively with criteria such as intensity or area in mm^2. We must determine ROI SN precisely as masks. The following figure (Fig. 5) shows an example of binary mask which has been created by Otsu´s algorithm[11] and are input to next part of processing. As input we have the matrix I with intensity values of pixels (uint8) and output is logical matrix => binary mask.

$$I = \begin{bmatrix} p_{11} & \cdots & p_{m1} \\ \vdots & \ddots & \vdots \\ p_{1n} & \cdots & p_{mn} \end{bmatrix} \quad (4)$$

[11] all methods for autothresholding on http://pacific.mpi-cbg.de/wiki/index.php/Auto_Threshold

ISBN: 978-1-61804-019-0

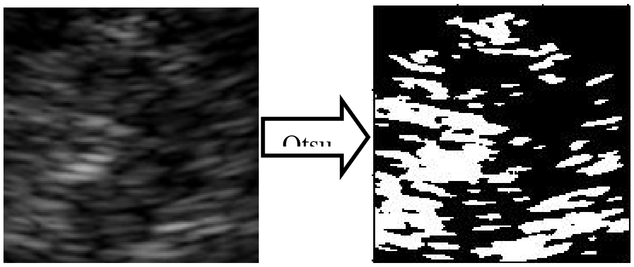

Fig. 5 Otsu thresholding

In MATLAB we apply graythresh function on loaded image:

```
[filename, user_canceled] = imgetfile;
orign=imread(filename);

otsu=graythresh(orign);
binim=im2bw(orign,otsu);
```

Also we use bwareaopen function during morphological operations to elimination of isolated P pixels in area, it will be helpful to better detection. For larger P we can get unusable result because small regions, defects, could be deleted. In our case, we set P=8. It is morphological operation open:

```
open8=bwareaopen(binim, 8);
```

Determining of potential pathological defects on intensity image is realized by bwperim function after morphology. The following image shows potential pathological defects and doctor can be add or delete objects in SN in windows with stem.

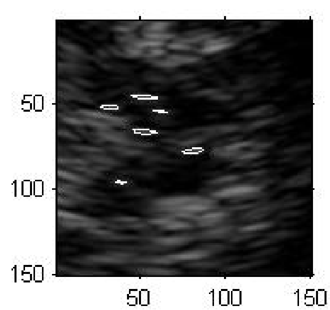

Fig. 6 Recognized defects in window with stem

A. Using a morphology and ROI detection

Now we will discuss about morphological processing and detection of SN. One way to detection is using a neural network with learning to detect SN shape with masks. It is supervised learning. We will show this processing in MATLAB too.

Morphological operations in MATLAB offer strong tool to this image processing[12]. We will use operations on binary images and at the end we will draw regions (defects) into intensity image. For morphology has been used bwmoprh function and auxiliary commands. For basic morphological operations, dilation and erosion, MATLAB offers special functions bwopen and bwdilate. These operations have no inverse. Mathematically we define dilation as union of image (I) and structural element (B):

$$I \oplus B = \bigcup_{b \in B} I_b \tag{5}$$

Erosion as an intersection of image and structural element. We will use both operations. Operation close and open are composition of basic dilation and erosion. Structural element is in MATLAB defined by function strel and is a subset of image and affect the effect of operation on region. Function strel has type and parameters about orientation (degrees).

```
se90 = strel('line', 3, 90);
se0 = strel('line', 3, 0);
```

Where line is a shape of structural element, 3 is a thickness to effect and 90/0 is an orientation of element.

The image recognition is well applicable problem for artificial neural network (ANN) using. The idea of ANN is motivated by biological neural networks in brain. It is very interesting trend not only for image processing, ANN are used for prediction, matching, clustering, etc. The basic element of ANN is artificial neuron also called as processing element (PE). These neurons are connected to network, this is a inspiration by synapses and dendrites in brain. We will not in details describe ANN theory; it is available in [11] and [14]. We only show a basic model of artificial neuron and show how to use ANN for our problem to detection of SN. In this type of network we use binary masks and supervised learning to shape recognition. For more information about using of ANN for computer vision and pattern recognition, see reference [2], it is focused to practical using of ANN for pattern matching, classification and recognition with different neural models.

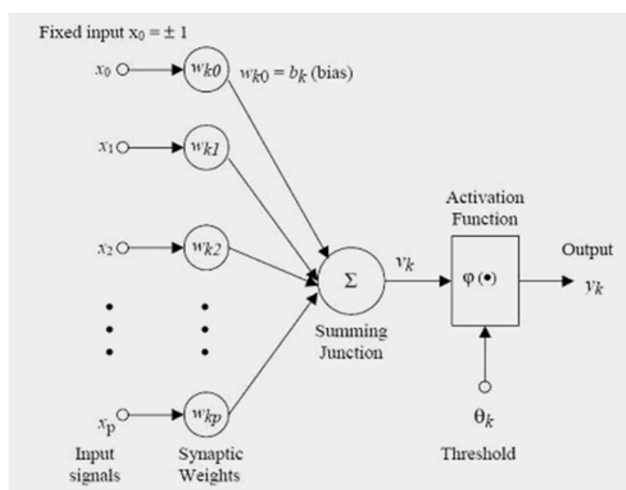

Fig. 7 Artificial neuron model[13]

[12] http://www.mathworks.com/help/toolbox/images/f18-12508.html

[13] http://www.learnartificialneuralnetworks.com/#Mathematical

ISBN: 978-1-61804-019-0

The most frequent topology of ANN is ML (multilayer) network with supervised learning. Training set for learning is given by inputs and desired response (targets).

$$S=\{ (I_1, D_1), (I_2, D_2),\ldots, (I_n, D_n)\} \tag{6}$$

ANN compares after each epoch of leasing an error which is define as difference between targets and output from network. We can stop learn if this error is minimal. We will use MSE (Minimal Square Error), usually used for this model. The MSE is expressed as sum of partial differences between real results and desired response. Formally we can express

$$MSE = \frac{1}{N}\sum_{i=1}^{N}(t_i - a_i)^2 \tag{7}$$

In MATLAB, MSE is defined in code by perform function

```
perform(net,targets,outputs).
```

We must set a threshold T_{MSE} for stop learning. If MSE is sufficiently low, we can consider output as good. In practice $T_{MSE} = 0.01$, thus

if $T_{MSE} \leq 0.01$ ***then*** stop_learning, next_epoch ***otherwise***.

Graphically we express MSE as learning curve (rate), in MATLAB (Neural Network Toolbox) displayed:

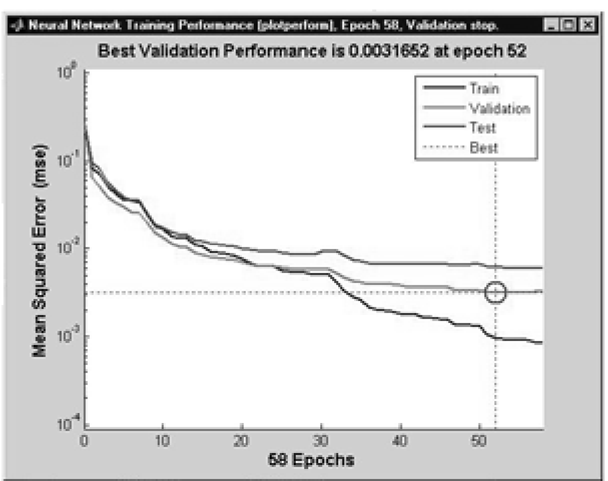

Fig. 8 MSE and learning rate in MATLAB

Result from ANN in our case is well detected SN in brain stem. We use the binary masks (equally as for morphology) and network learns it. Masks we create manually and set inputs and targets with initializing net by init command and getwb for weights. Now we show an example of mask which will be input.

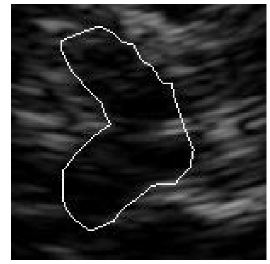
Fig. 9 An example of ROI SN mask

In this situation, we gradually improve settings of ANN and learning. The purpose is higher level of detection. Morphological operations are well usable for this problem how has been showed in previous chapter.

We have a GUI application created in MATLAB GUIDE which contains morphology with selecting objects as we described. We improve ANN. Application works with common formats of images and we will extend it for DICOM support also. MATLAB for this purpose allows import and export DICOM files. Morphology is the best way to solution with well created masks.

B. *Defects assessment*

Searched defects in SN are critical for potential PD diagnosis. Doctor can decide that patient has PD or not and level of damaging. Criteria are area of defects and percent of total area. Also can compare results with another modality, for example CT or MRI, and analyse correlation.[14] Simply we can appoint basic if-then rule for area A of SN:

if $A \leq 0.19\ cm^2$ ***then*** PD=true, false ***otherwise.***

Threshold for area A of SN is generally $0.19\ cm^2$. It is a primary criterion to decision about features of PD. The next criterion is number and area of well recognized defects in SN. In MATLAB we can find the area with bwarea function and these regions will be delineating in intensity images.

V. Conclusion

The purpose of this work is showing the way of image processing for neurosonographical images in MATLAB. This solution includes traditional methods for processing and eventuality of using ANN to detection of SN in brain stem. Principle of this solution is showing morphological operations to detection of pathological defects. MATLAB provides a wide scale of tools for it. Our designed application is in development, we will design better recognition. Regardless, application is useable and shows options in MATLAB for image processing. This work has an interdisciplinar character between medicine and informatics.

To next processing, we will add DICOM support and better detection of SN with ANN. DICOM support is very important for medical imaging and processing, doctors usualyy have only DICOM images. Morphological operations provide searching of defects on ROI area with computing of area of each object. Furthermore, we will set an optimal threshold to

[14] http://www.ncbi.nlm.nih.gov/pubmed/20040773

ISBN: 978-1-61804-019-0

finding if Otsu´s method will be inexact with larger dataset. In practice, this threshold will be low.

References

[1] Becker, G.,:"Degeneration of substantia nigra in chronic Parkinson's disease visualized by transcranial color-coded real-time sonography", 1995, Journal of Neuroimaging 45.

[2] Bishop, Ch., "Neural Networks for Pattern Recognition", 1996, Oxford University Press, USA; 1 edition, ISBN-13: 978-0198538646.

[3] Blahuta J., Soukup T., Čermák P., "The recognition of substantia nigra in brain-stem ultrasound images based on Principal Component Analysis", Mathematical Models for Engineering Science, MMES´10, 2010, Institute for Environment Engineering, Economics and Applied Mathematics, ISBN: 978-960-474-252-3, pp. 94-98.

[4] Blahuta J., Soukup T., Čermák P., "The image recognition of brain-stem ultrasound images with using a neural network based on PCA", Recent Researches in Communications, Electrical and Computer Engineering, EMEH ´11, 2011, ISBN: 978-960-474-286-8, pp. 134-142.

[5] Diamantaras, K.: "Principal Component Neural Networks: Theory and Applications", 1996, ISBN:0-471-05436-4.

[6] Gelb, D., O. E. G.-S.: 1999, "Diagnostic criteria for Parkinson´s disease, Archives of Neurology" 56(1), 33–39.

[7] Grossberg, S., Carpenter A.: "Neural Networks for Vision and Image Processing", 1992, ISBN-13: 978-0262531085.

[8] Ibáñez, L., Schroeder, W., Ng, L., Cales, J.: "ITK 1.4, ITK Software Guide", 2003, ISBN:1-930934-10-6.

[9] Montgomery, C. D., Runger, C. G., "Applied Statistics and Probability for Engineers", 2006, Wiley; 4th Edition, ISBN-13: 978-0471745891.

[10] Petrou M.,S.G.P.,Wiltshire, Image processing, Dealing with texture, 2006, ISBN: 0-470-02628-6.

[11] Principe J. C., Euliano N. R., Lefebvre W. C., "Neural and Adaptive Systems: Fundamentals Through Simulations", 2000, John Wiley & Sons, Inc.

[12] Schreiber, J., Sojka, E., Ličev, L., Škňouřilová, P., Gaura, J., Školoudík, D.: "A new method for the detection of brain stem in transcranial ultrasound images", Proceedings of Biosignals 2008, 2008.

[13] Sojka, E.: "A motion estimation method based on possibility theory", 2006, Proceedings of IEEE ICIP, pp. 1241.

[14] Smagt P. v d., Kröse B., "An introduction to neural networks", 1996, The University of Amsterdam; 8th Edition.

[15] Školoudík, D.: "Reproducibility of sonographic measurement of the substantia nigra", Ultrasound in Medicine & Biology (9), 2007, pp. 1347–1352.

[16] Tabachnick, G. B., Fidell, S. L., "Using Multivariate Statistics, 5th Edition", 2006, Pearson Education; 5th Edition, ISBN-13: 978-0205459384.

[17] Walter U, Wittstock M, Benecke R, Dressler D: "Substantia nigra echogenicity is normal in non-extrapyramidal cerebral disorders but increased in Parkinson's disease.", J Neural Transm. 2002 , 109:, pp. 191-196.

[18] Webster DD: "Critical analysis of the disability in Parkinson's disease"., Mod Treat, 1968, 5:, pp. 257-282.