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Title: VCfMRI: A Matlab Toolbox for Visualization and Conversion of fMRI Data Modalities

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Highlights

- A novel conversion and visualization fMRI (VCfMRI) toolbox is proposed.
- VCfMRI is enabled to read, write 3-D volume data and multi conversion operations.
- About 62 analyses functions and 7 GUI tools for fMRI modalities are implemented.
- VCfMRI provides an easy way of handling these type of data.

Plain Language Summary

Functional Magnetic Resonance Imaging (fMRI) is a robust noninvasive and modern technique for imaging of brain functions. The complexity of the raw Functional Magnetic Resonance Imaging (fMRI) data leads to significant challenges faced with multi operations with these data, such as image conversion, read and write, extract information, and so on. To overcome these difficulties and challenges, an indispensable initial stage in processing the fMRI dataset is to convert images from the complicated form (raw data) DICOM to the much simpler NIfTI (.nii or .nii.gz) or ANALYZE (.img/.hdr) format.

In this work, a novel conversion and visualization fMRI (VCfMRI) toolbox is proposed. The VCfMRI tool is enabled to read, write 3-D volume data (.dicm, .nii, .img, hdr and .mat format), as well as multi conversion operations between them, are performed in the same package. This toolbox is designed and implemented under the MATLAB platform and 64-bit Windows environment for visualizing fMRI time series data.

In the current work, real fMRI data are used and classified into three groups, which named night group, the healthy control group, and full day group. The data acquired by MRI scanner type Siemens/3T in National Magnetic Resonance Research Center (UMRAM) at Turkey/ Ankara. About 62 analyses functions have been implemented and incorporated in analysis about 7 GUI tools for multiple conversions of fMRI modalities, reading/writing and viewing in all fMRI data formats, visualizing 3-dimensional (sagittal, coronal and horizontal slices) statistical and non-statistical neuroimaging, thresholding and overlaying viewing.

This work enables the user to visualize and deals with fMRI data efficiently, especially for physicians, healthcare specialists, and researchers who faced challenges about how handling with these type of data.

Abstract

In this work, a novel conversion and visualization fMRI (VCfMRI) toolbox is proposed. The VCfMRI tool is enabled to read, write 3-D volume data (.dcm, .nii, .img, hdr and .mat format), as well as multi conversion operations between them, are performed in the same package. In the current work, real fMRI data are used, and all data are acquired by MRI scanner type Siemens/3T in National Magnetic Resonance Research Center (UMRAM)-Bilkent University. About 62 analyses functions have been implemented and incorporated in analysis about 7 GUI tools for multiple conversions of fMRI modalities, reading/writing and viewing in all fMRI data formats, visualizing 3-dimensional (sagittal, coronal and horizontal slices) statistical and non-statistical neuroimaging, thresholding and overlaying viewing. The presented package is a simple tool to address several issues related to complexity in visualizing and conversion between multi-formats of fMRI data. This work enables the user to visualize and deals with fMRI data in an easy way, especially for physicians, healthcare specialists, and researchers who faced challenges about how handling with these type of data.

Keywords: Brain Imaging, Information Systems, Functional Magnetic Resonance Imaging, Medical Informatics Computing.

1. INTRODUCTION

Medical imaging is well-known in both the clinical and other research areas with several equipment constructors providing a varied change of modalities. Many of the general tools are used for technical image processing, analysis and visualization involve images to be stored in the NIfTI and ANALYZE file format; while scanners accustomed obtain these images usually export data in the DICOM format. These two formats are appropriate for their specific function: DICOM is comprehensive and effusive, whereas NIfTI is smooth and straightforward to support. Thus, a mutual first step in every neuroimaging analysis is to convert the images from DICOM to NIfTI format (Li et al., 2016; Mildenberger, Eichelberg, & Martin, 2002; Ashby, 2014; Larobina & Murino; 2014). This paper describes the Visualization and Conversion of fMRI Data Modalities (VCFMRI), a new software package designed and optimized to statement various issues faced while visualizing and conversion multi-modal neuroimaging data, especially the complexity problem. The grouping of analyses from many imaging modalities is a significant and developing trend in neuroimaging (McDonald, 2008; S.M. & B.R., 2007). Researchers are aware of the limitations of different imaging techniques and their related analysis approaches (Orden, 2006). Multi-modal methods are used to achievement differences in results acquired from different methods (Liu Z, Kecman F, He, 2006) and actually organize for joining evidence about researchers' hypotheses. Several of neuroimaging analysis packages are presented to researchers, assisting analysis of data from a complex and varied range of data acquisition systems. The Neuroimaging Informatics Tools and Resources Clearinghouse (NIFTI, n.d.) introduced numerous of these tools. Commercial analysis software packages comprise ANALYZE (AnalyzeDirect, n.d.) and BrainVoyager (BrainVoyager, 2012). There are several open-source analysis toolboxes widely used for MATLAB; which are exemplified by Statistical Parametric Mapping (SPM) (FIL Methods Group, n.d.), Fieldtrip (Oostenveld et al., 2011), EEGLAB (Delorme & Makeig, 2004), mrVista (Teo, Sapiro, & Wandell, 1997) and NUTMEG (NUTMEG, n.d.) Stand-alone, cross-platform analysis packages comprise FSL and Free Surfer (FreeSurfer, n.d.; FSL–FslWiki, n.d.). Besides to analysis packages, several standalone visualization packages have been developed, some of them complement particular analysis packages (e.g., FSL's FSLView (FslView, n.d.) and others individually of analysis packages MRICron (MRIcron Index Page, n.d.) and 3D Slicer (3D Slicer, n.d.). Both analysis and stand-alone visualization packages are often modified results advanced by a site to report their particular requirements.

The problem of whom to overcome these difficulties and challenges is still open. An indispensable initial stage in processing the fMRI dataset is to convert images from the complicated form (raw data) DICOM to the considerably simpler NIfTI (.nii or .nii.gz) or ANALYZE (.img/.hdr) format. So, in this work, a new conversion and visualization fMRI (VCfMRI) toolbox is proposed and implemented. The paper is ordered as follows: 1) the fMRI data formats conversion has been described in Section 2; 2) the details of the software framework design and results have been presented in Section 3; 3) discussions and conclusions are presented in Section 4.

2. FMRI DATA FORMATS CONVERSION AND READING

Image file formats arrange for an identical system to collect the information of an image in a computer file. A medical image is represented typically as either an image plane or volume. The image plane is made of one or more images on behalf of the analysis of an anatomical volume. The volume is made of a series of images on behalf of thin slices. The file format refers to in what way the image data are structured inside the image file and in what way the pixel data should be construed by software for the accurate loading and visualization.

FMRI image file formats can be divided into two categories, as shown in Figure 1. The first one is the formats planned to systematize the images created by diagnostic modalities, e.g., Dicom (Bidgood et al., 1997). The second one is the formats trained with the intention to enable and support post-processing analysis, e.g., Analyze (Robb et al., 1989; Whitcher, Schmid & Thornton, 2011; Eloyan et al., 2014), Nifti (Neuroimaging Informatics Technology Initiative, n.d.; Filippi, 2009).

Medical image files are generally stored with one of the next two arrangements. One where a single file holds together the metadata and image data, using the metadata stored at the beginning of the file. This paradigm is used by Dicom and Nifti file formats, even if it is acceptable by other formats. The second arrangement stores the metadata in one file while the image data in a second one. The Analyze file format customs the two-file paradigm (.hdr and .img).). In this part, characterize some of the most popular formats: Analyze, Nifti, and Dicom. The features of the termed file formats are summarized in Table 1.

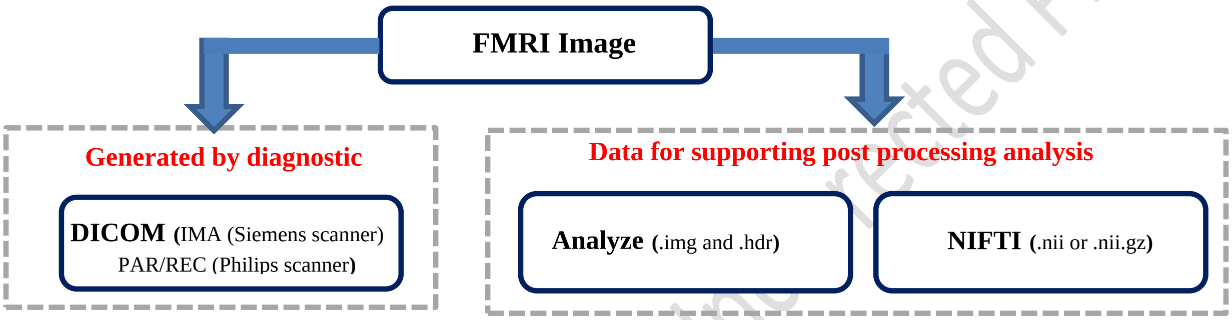

Figure 1: fMRI Image Data categories

Table 1 characteristics of fMRI data formats

Format Name	Data types	Origin	Header	File Extension	Save Data	Handling
DICOM	Both signed and unsigned integer is (8, 16; and 32-bit, float not supported)	American College of Radiology (ACR)/ National Electrical Manufacturers Association (NEMA)	A binary format, Variable-length	IMA (Siemens scanner) PAR/REC (Philips scanner)	Raw image data in DICom is saved as a 2D image slices	Handling several hundreds of DICOM files
Analyze	signed integer (16 and 32-bit), Unsigned integer(8 bit), complex (64-bit) , float (32-, 64-bit)	Analyze software, Mayo Clinic	A binary format, Fixed-length: about 348 byte	Two extension (.hdr and .img)	Image data in Analyze is saved as a 3D image	Handling two images of files
NIfTI	Both signed and unsigned integer (8 to 64 bit), complex (64 to 256 bit), float (32 to 128 bit)	NIH Neuroimaging Informatics Tools Initiative	A binary format, Fixed-length: about 352 byte	.nii or .nii.gz	Raw image data in NIfTI is saved as a 3D image (when it is used in SPM but 4 D image if it is used in FSL)	Handling a single NIFTI file

General purpose programming languages like MATLAB do not support any of these formats. Therefore, a researcher who writes his or her MATLAB code for any data analysis step has to convert from one of these standard formats to a format that is MATLAB compatible. Popular software packages such as SPM (FIL Methods Group, n.d.; Ashburner, 2012) and FSL (Jenkinson et al., 2012) provide such code. The data that come off the scanner with most MR systems are in DICOM format. So, typically, the first step in the data analysis process is to convert the data from DICOM to some other format (Graham, Perriss, & Scarsbrook, 2005; Behroozi M, Daliri M R, 2011; Behroozi M, 2013). Fortunately, there are various software options for performing this task. Throughout this conversion process, it is possible that some supporting information would be lost. For example, the Analyze format tends to have smaller headers than those of DICOM or NIfTI. So, when converting from either DICOM or NIfTI to Analyze, it is possible that some of the header information would be lost. Much more importantly, however, all of the intensity values collected from the scanner will be retained.

The initial stage for converting DICOM to NIFTI format is to classify DICOM files into different series. The DICOM concatenation involves a pack of DICOM images that which were created altogether with the same MRI machine in the same process. There are two ways to classify DICOM to specific series; first, it is the most authoritative way of sorting series by DICOM objects like UID. The second way had been done by gathering objects Patient Name, Series Number, and Study ID. Within every set of the series, if possible, it requires to classify images to different volumes. The instance number usually determines this. For certain kinds of files, one or may be more than one of the following DICOM objects are necessary for a reliable sorting of images in a series as echo number, acquisition number, image type, and image position patient. After that, the images in a series can be accumulated in an image containing up to seven dimensions.

For projection voxel indices into position in a coordinate system, the transformation matrix is utilized; the DICOM Patient Coordinate System is shown in Figure 2.

Typically need the following DICOM objects to structure the transformation matrix. The first one of DICOM object is image orientation patient which comprises two triplets $(r_x\ r_y\ r_z\ c_x\ c_y\ c_z)$ and which the main function is to encode the cosines orientation of the column and row of the image slice. The second DICOM object is the image position patient of the first slice in a given *volume* (x_1 , y_1 *and* z_1), is the coordinate of the *x*, *y*, and *z* in the voxel of the top-left corner of the first slice. Through the two above parameters, it is easy to determine the position of certain slices in the patient coordinate system. To locate the position of the volume, the image position patient parameter of the other slice is usually required. The size of a voxel is stored in pixel spacing of DICOM object inside the slice plane (v_r , v_c).The following Equation (1) R_{DICOM} is used to construct the transformation matrix of DICOM coordinates, and *n* refers to the sum of the slices in the volume.

$$R_{DICOM} = \begin{bmatrix} r_x v_r & c_x v_c & \frac{(x_n - x_1)}{(n-1)} & x_1 \\ r_y v_r & c_y v_c & \frac{(y_n - y_1)}{(n-1)} & y_1 \\ r_z v_r & c_z v_c & \frac{(z_n - z_1)}{(n-1)} & z_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

The following Equation (2) R_{NIFTI} is used to construct the transformation matrix of NIfTI coordinates. Firstly, the positive sign of the first two rows in equation 1 (R_{DICOM}) is changed to negative sign in order to reflect the dissimilarity in the NIfTI coordinate system. NIFTI system is used RAS coordinate which is a positive coordinate and refers to right, , anterior and superior. The R_{NIFTI} is based on NIfTI header, where the first three rows refer to rows of affine transform which are three items in the header of NIFTI file. The third column is similar between R_{DICOM} and R_{NIFTI} which comprise the slice thickness info. The thickness of slice usually is determined by the DICOM object spacing.

$$R_{NIFTI} = \begin{bmatrix} -r_x v_r & -c_x v_c & -\frac{(x_n - x_1)}{(n-1)} & -x_1 \\ -r_y v_r & -c_y v_c & -\frac{(y_n - y_1)}{(n-1)} & -y_1 \\ r_z v_r & c_z v_c & \frac{(z_n - z_1)}{(n-1)} & z_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

In general, there are many software packages listed in Table 2 support multi fMRI data format, whether open source or commercial versions in neuroscience area or fMRI area for visualization or conversion data, but all of them do not have all possibilities of the conversion fMRI data format or all displaying modalities. However, the main contribution in the current work multiple conversion processes for all fMRI data formats are proposed and tested successfully in our lab.

In the current work, real fMRI data are used and classified into three groups, which named night group, the healthy control group, and full day group. Night group consists of ten subjects, and healthy control groups consisted of also ten subjects while the all-day group is 11 subjects. The experiment stimuli were chewing and biting, all data are acquired by MRI scanner type Siemens/3T in National Magnetic Resonance Research Center (UMRAM)-Bilkent University.

Table 2 List programs that support multi fMRI data formats

Software Program	Format
SPM	Analyze (.img/.hdr),NIFTI(.nii)
FSL	NIFTI (.nii or nii.gz)
MRICRO	Analyze (.img/.hdr)
MRICRON	NIFTI (.nii or nii.gz)
ANALYZE	Analyze (.img/.hdr)
Mri3dx	Analyze (.img/.hdr)
NIFTI	NIFTI (.nii)
Slice Overlay	Analyze (.img/.hdr)
FreeSurfer	NIFTI (.nii)
AFNI	Analyze (.img/.hdr), NIFTI(.nii)
oro.nifti	NIFTI (.nii)
arf3DS4	NIFTI (.nii)

There are 12 conversion processes of fMRI data format performed in current work (Table 3). This software package contains all conversion processes so that it will be the first in the literature. Another vital purpose of VCfMRI tool is introduced to visualize all modalities of fMRI data format in one package.

Table 3 List of 12 conversion processes of fMRI data formats

Conversion Process Name	Input Data	Output Data
DICOM to .MAT	DICOM	.MAT
NIFTI to .MAT	NIFTI	.MAT
Analyze (.img/.hdr) to .MAT	Analyze (.img/.hdr)	.MAT
DICOM to NIFTI	DICOM	NIFTI
DICOM to ANALYZE	DICOM)	ANALYZE
.MAT to NIFTI	.MAT	NIFTI
Analyze (.img/.hdr) to NIFTI	Analyze (.img/.hdr)	NIFTI (.nii)
NIFTI to 2 D DATA	NIFTI	2 D DATA
Analyze (.img/.hdr) to 2 D DATA	Analyze (.img/.hdr)	2 D DATA
NIFTI to Analyze (.img/.hdr)	NIFTI(.nii)	Analyze (.img/.hdr),
3D to 4D	3D with multi volumes(multi files)	4D with all volumes in one files
4D to 3D	4D with all volumes in one file	3D with multi-volumes(multi files)

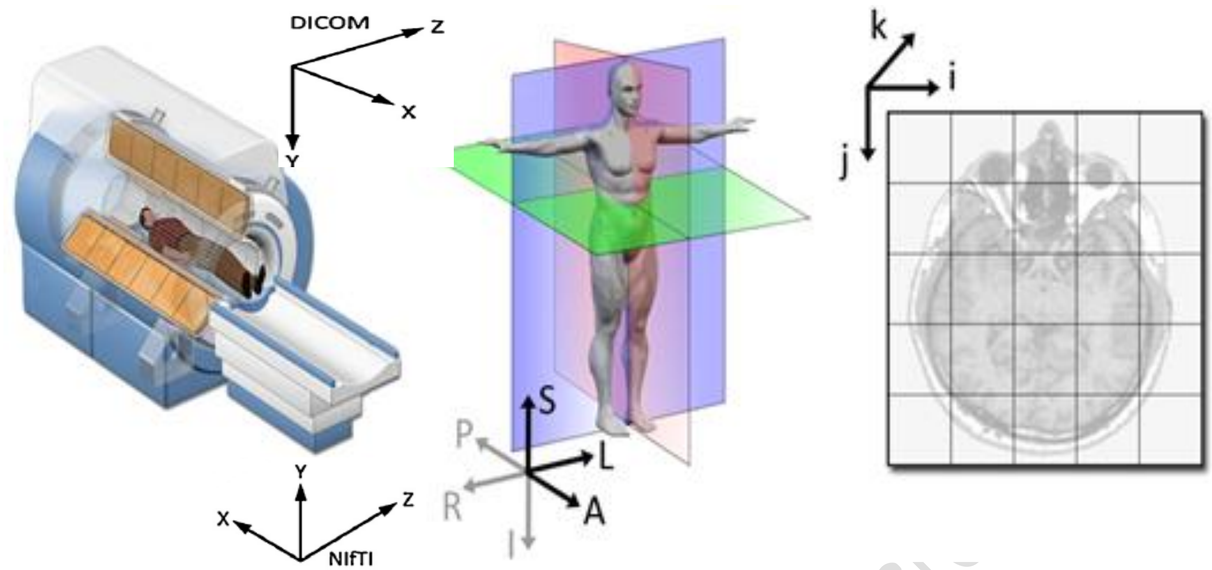

Figure 2 DICOM and NIFTI patient coordinate system

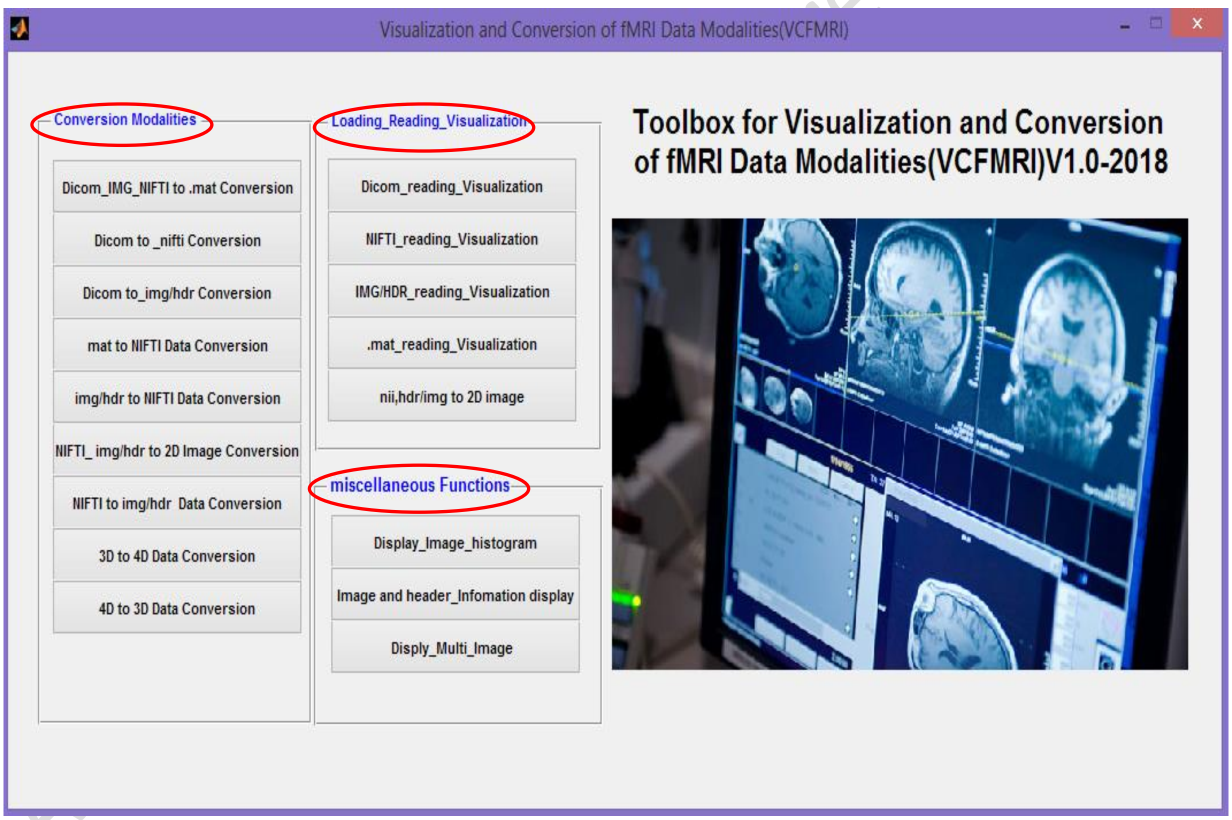

Figure 3 Startup window of VCfMRI tools

3. SOFTWARE FRAMEWORK DESIGN AND RESULTS

The conversion and visualization fMRI (VCfMRI) tools consist of three main parts: first, conversion modalities; second, loading, reading, writing, and visualization all fMRI data formats, third miscellaneous functions. The startup window of VCfMRI tools consists of multiple push buttons is shown in Figure 3.

At the start of the application, the first step provides the multiple conversion operations of all fMRI data formats (.dcm, .nii, .img, hdr, and .mat format). This step is performed through nine buttons to perform 12 mathematical conversion processes that reflect all conversion possibilities between them (Figure 4).

When the user clicks the "DICOM_IMG_NIFTI to .mat Conversion" button, the .mat conversion image conversion window in Figure 5 appears. From the pop-up menu, the user can select one of the three types of fMRI data (.dcm, .nii, and .img/hdr). After appropriate selections, the dataset is loaded, and the header of this file is read and converted to the .mat format.
The clicks on the "DICOM to _NIFTI Conversion" button, the DICOM selection window appears. In the developed tool, a convenient feature for selecting only DICOM files exists. After the file selection process, the dataset is read and converted to .nii file format.
When the user clicks the "DICOM to img/hdr Conversion" button, the DICOM selection window appears. The user can select the desired DICOM files, and the selected files are loaded. Subsequently, the dataset is read and converted to the img/hdr file format.

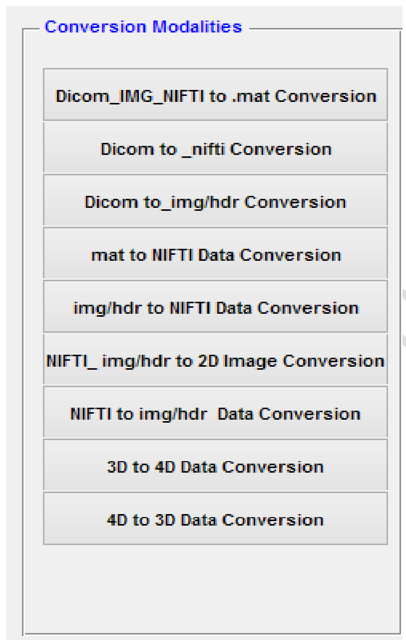

Figure 4 Conversion Modalities section

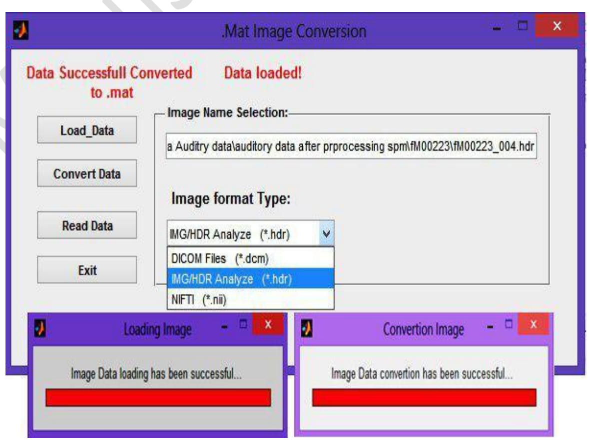

Figure 5 DICOM_IMG_NIFTI to .mat Conversion

The clicks on the ".mat to NIFTI Data Conversion" button, the .mat selection window appears. In the developed tool, a very convenient feature for selecting only .mat files exists, as shown in Figure 6. After the file selection process, the dataset is read and converted to .nii file format.
The clicks on the "img/hdr to NIFTI Data Conversion" and "NIFTI to img/hdr Data Conversion" buttons are achieved by the same way of the previous button. The presented tool gives a very convenient feature for selecting only .img/hdr files and .nii, respectively. After the file selection process, the dataset is read and converted to .nii file format and

separate header and image data files (.img/hdr) respectively.

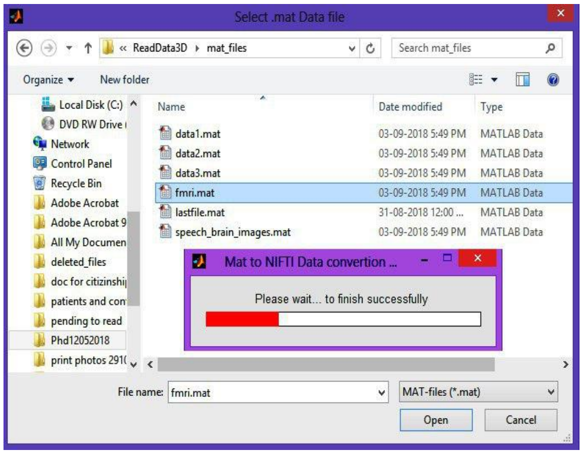

Figure 6 Selection mat Data window

The clicks on "NIFTI_ img/hdr to 2D Image Conversion" button, enables users to convert fMRI data formats (NIFTI and Analyze) to 2D Image format. This conversion is different from the above conversion processes because the output results appear as a 2-dimensional data file.
When the user clicks this button, the "Creating 2D fMRI data" GUI window appears (Figure 7). The desired "Create img to 2D Image" or "Create nii to 2D Image" button can be selected by the user, and the selected dataset is loaded and read (.img/hdr or .nii). A new 2D matrix data image is created, and the output result is displayed as a 2D fMRI image (Figure 7) by clicking the "View fMRI Data" button.

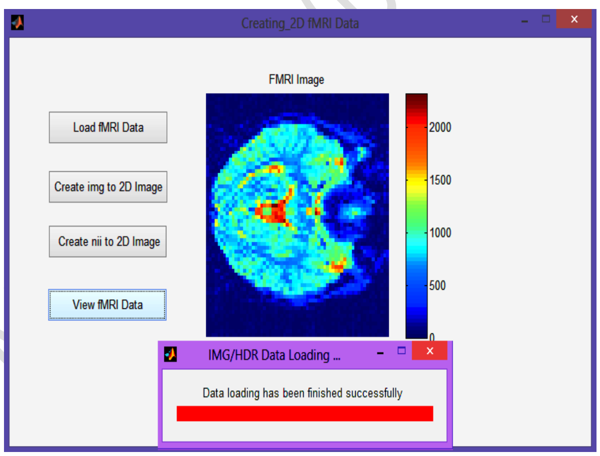

Figure 7 Creating 2D fMRI Data

A "3D to 4D Data Conversion" button enables the user to convert fMRI data format nii with all volumes to the nii.gz. This means all fMRI data files (multi-volume files) can be converted to a compressed file (one file). When the user is clicking on this button, a 3D to 4D conversion window appears. The desired 3D files can be selected by the user, and the selected 159 files (volumes) in our case are loaded and saved as the one output .nii.gz file.
Finally and inverse to the last button, a "4D to 3D Data Conversion" button enables the user to convert fMRI data format .nii.gz (compressed one file) to .nii with multi-volume files. When the user is clicking on this button, a 4D to 3D conversion window appears. The desired 4D file can be selected by the user, and the selected .nii.gz file are loaded and saved as the 159 output .nii files in our case.

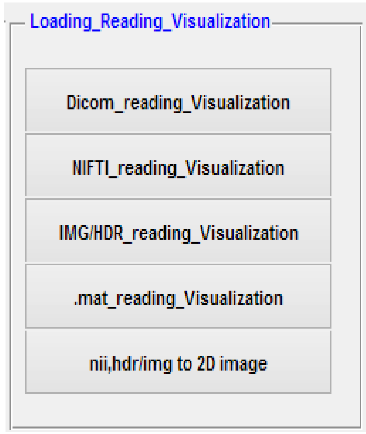

Figure 8 Loading_ Reading_ visualization part

The second part in the designed tool is "Loading_ Reading_ Visualization" module, which consists of multiple visualization operations of all fMRI data formats (.dcm, .nii, .img, hdr, and .mat). This part controlled with five buttons to perform five visualization processes that reflect all visualization possibilities for all fMRI data (Figure 8). In the developed tool, a beneficial feature for helping the users also exists. The user can read header data and write all types of fMRI data formats in a simple GUI design.

When the user clicks the "Dicom_ reading_ Visualization" button, the "Loading, Reading and Viewing DICOM Data" GUI window appears (Figure 9). In the designed GUI window, many features of DICOM fMRI data processing exists. The desired DICOM folder (at the left of Figure 9) can be selected by the user, and the program makes analyses for calculating the number of images. When the analyses are finished, the selected data are saved automatically in the working directory. For the desired number of images, DICOM series images are easily displayed and read the header (at the right of Figure 9) which includes all information about this image. In the presented GUI, a very convenient feature to deal with the large volume of the DICOM header work out. Also, some get-up-and-go buttons can be selected by the user to navigate between rows of the header or use the scroll bar of the list box of header information.

When the user clicks the "NIFTI_ reading_ Visualization" button, the NIFTI fMRI window appears (Figure 10). For the desired .nii file, NIFTI image is readily displayed and read the header.

When the user clicks the "IMG/HDR_ reading_ Visualization" button, a new GUI window appears (Figure 11). In the designed GUI window, many features of IMG/HDR fMRI data processing exists. The "Load fMRI Data" button at the left of Figure 11, enables the user to select a pair of fMRI files (.img and .hdr). After appropriate selection, the program makes analyses for calculating the number of the voxel, applied threshold, and the dimension of data. In the presented GUI, a very convenient feature to display the IMG/HDR fMRI Data in 3-dimensional (sagittal, coronal, and horizontal slices) exists. An additional important feature of this GUI tool (at the right of Figure 11)) is that it presents the user an easy way to deal with contrast, brightness, and color map property (8 color map is used).

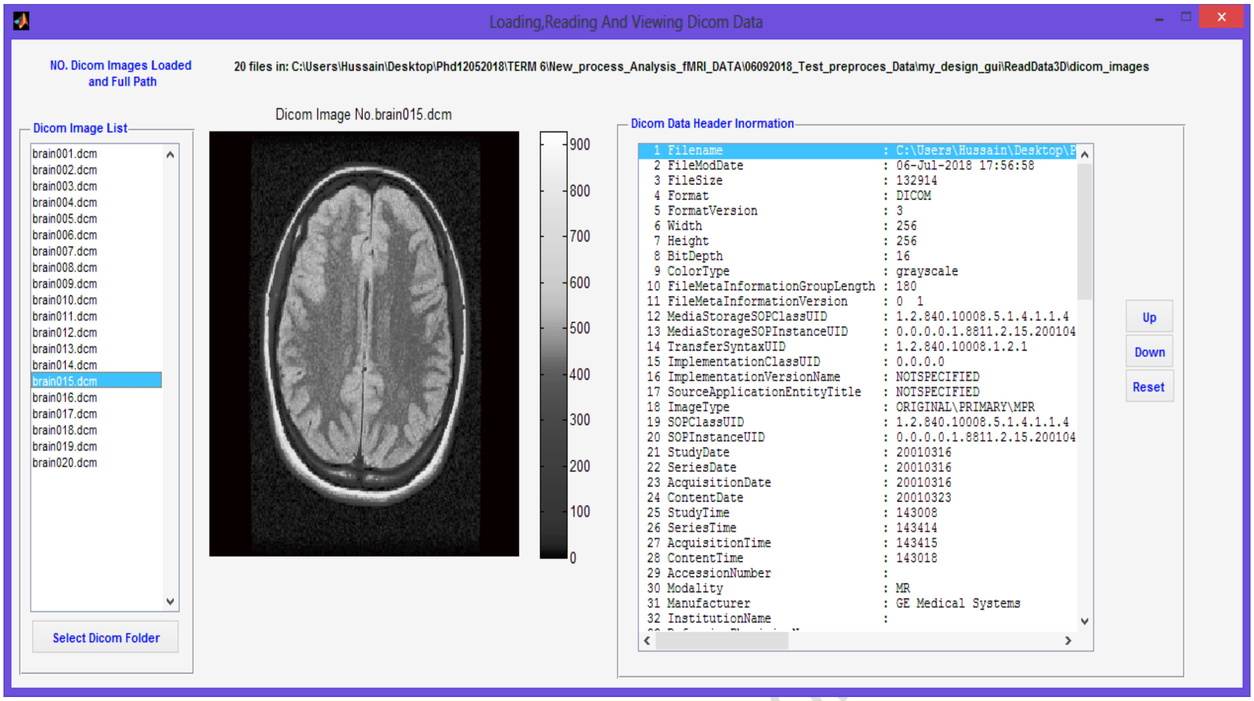

Figure 9 Dicom_reading_Visualization

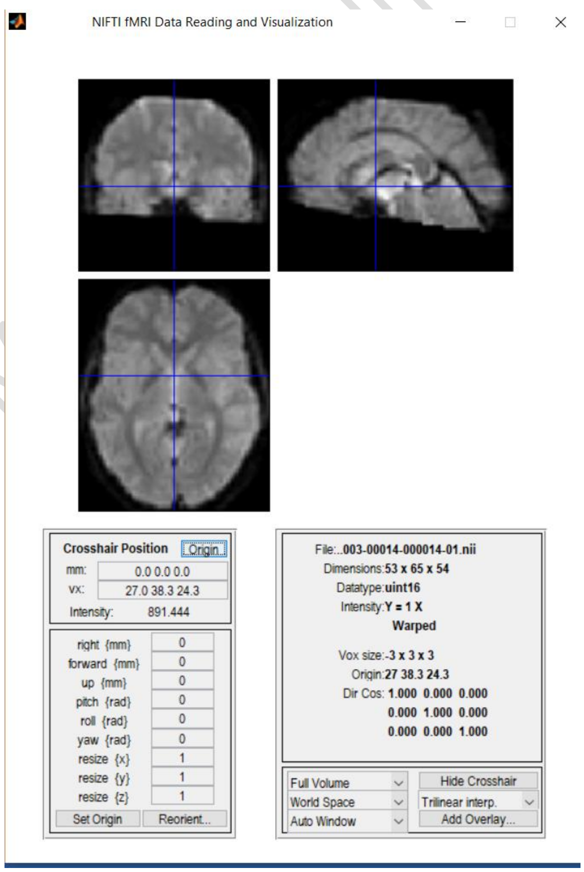

Figure 10 NIFTI_ reading _Visualization

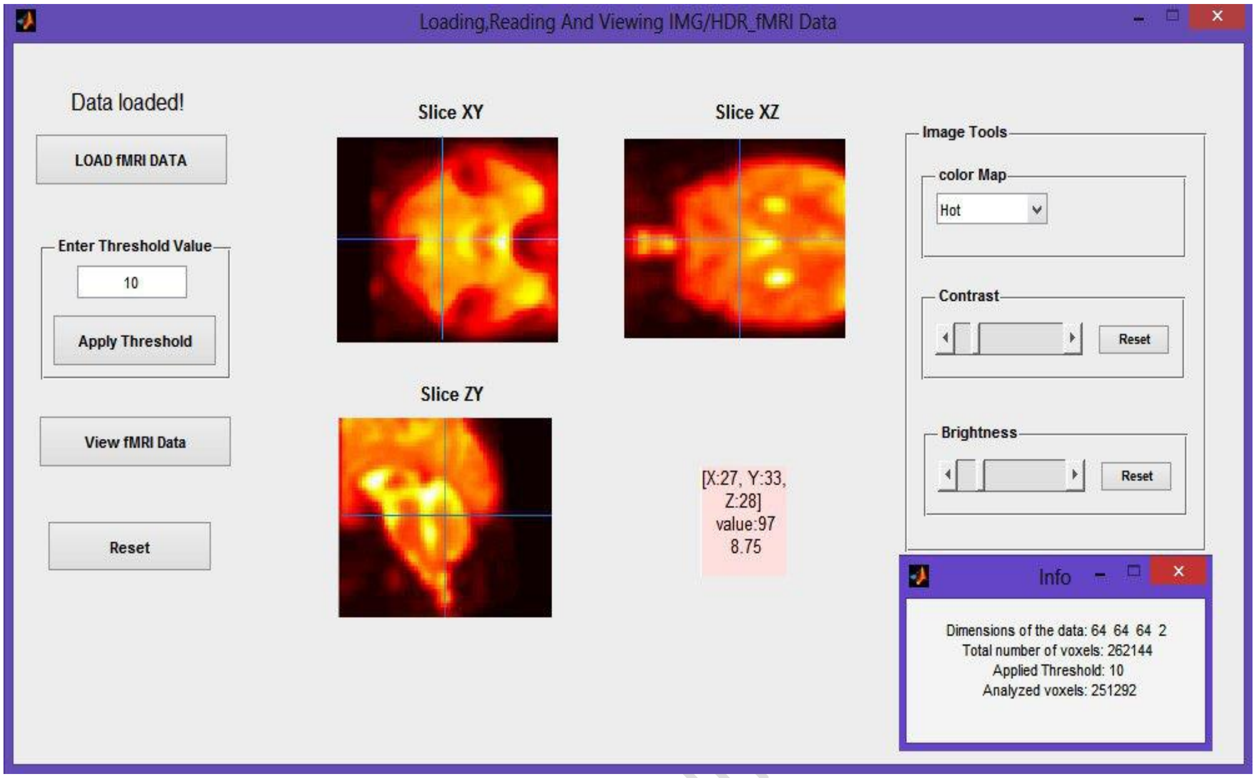

Figure 11 IMG/HDR_reading_Visualization

When the user clicks the ".mat_ reading_Visualization" button, a new GUI window appears (Figure 12). In the designed GUI window, many features of .mat fMRI data processing exist. The "Load fMRI Image" button at the left of Figure 12 enables the user to load .mat data. Normally, both functional and structural fMRI dataset are stored in the same .mat file. After appropriate file selection, the program makes analyses for calculating the dimension of the functional and structural dataset. In the presented GUI, a very convenient feature to display the .mat fMRI Data by slices way work out. An additional important feature of this GUI tool is that it provides the user an easy way to display the desired fMRI data slice by slice (at the right of Figure 12), and navigates between them through control buttons (+ and -).

When the user clicks the "nii, hdr/img to 2D image" button, a new GUI window appears (Figure 13). In the designed GUI window, the "Load fMRI Data" button at the left of Figure 13, enables the user to load .img/hdr or .nii file. After appropriate selection, the user can select either "Create img to 2D Image" or "Create nii to 2D Image" button to create a new 2D matrix data image. The created 2D image can be displayed by clicking "View fMRI Data" button.

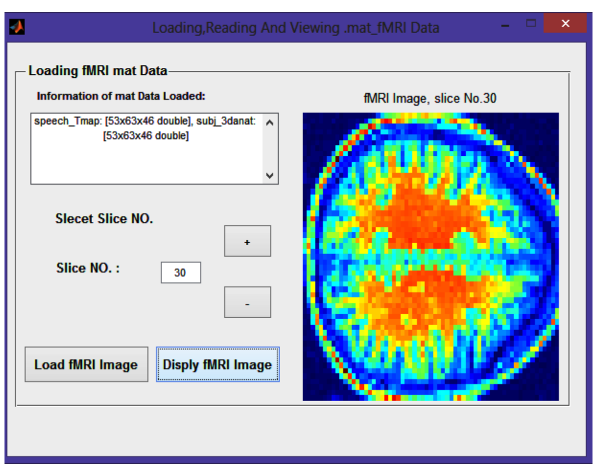

Figure 12 mat_reading_Visualization

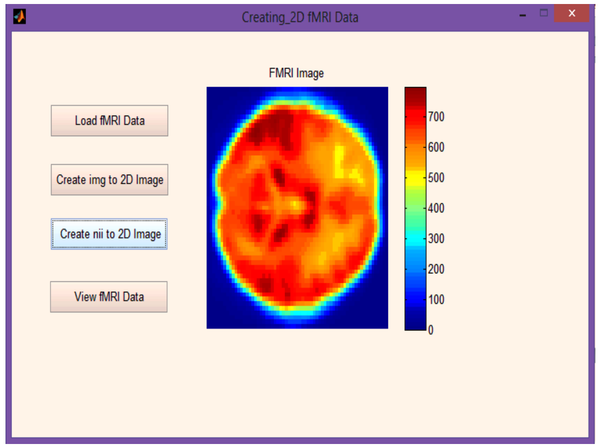

Figure 13 nii,hdr/img to 2D image Visualization

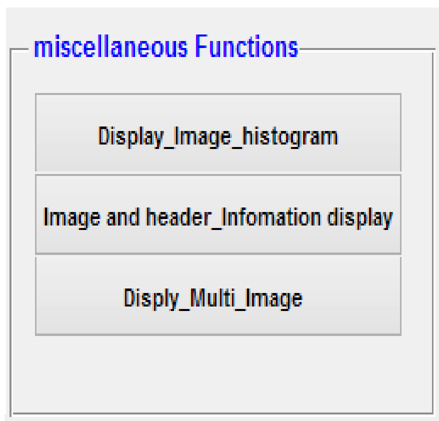

Figure 14 miscellaneous Functions part

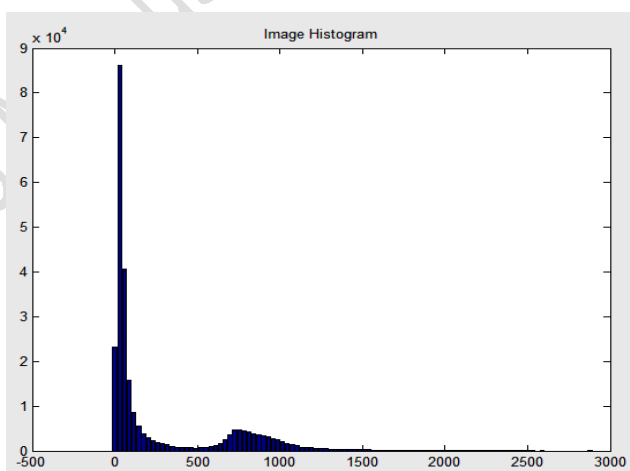

Figure 15 Display_Image_histogram

The third part of the tool is "Miscellaneous Functions" part, which includes display the image histogram, display the image and header information, and display more than one image in the same figure (Figure 14). When the user clicks the "Display_ Image_ histogram" button, image histogram function introduces. As seen in Figure 15, the user can display the histogram of any fMRI image format.

When the user clicks the "Image and header_ Information display" button, the "Image and header Information" window appears. As seen in Figure **16**, the user can read any format of fMRI image with its important header information; such as file name, dimension, data type as well as the crosshair position of the image and other functions. When the user clicks the "Disply_ Multi_ Image" button, the "Multi fMRI Image" window appears. As seen in Figure **17**, the user can display more than one fMRI images in the same graph. Also, the user can compare between two images, such as functional and structural fMRI images or display multi-contrast images to see a different contrasting area of multi-contrast images.

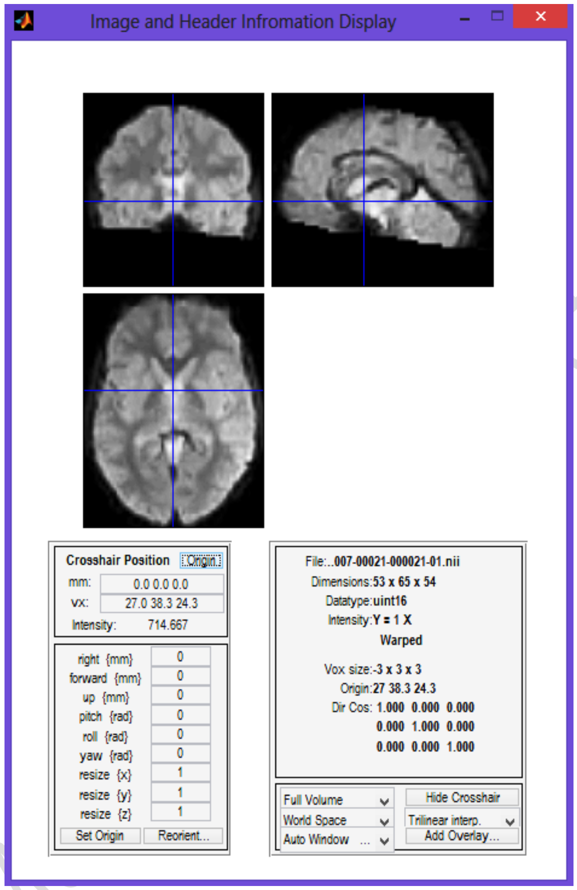

Figure 16 Image and header_ Information viewer

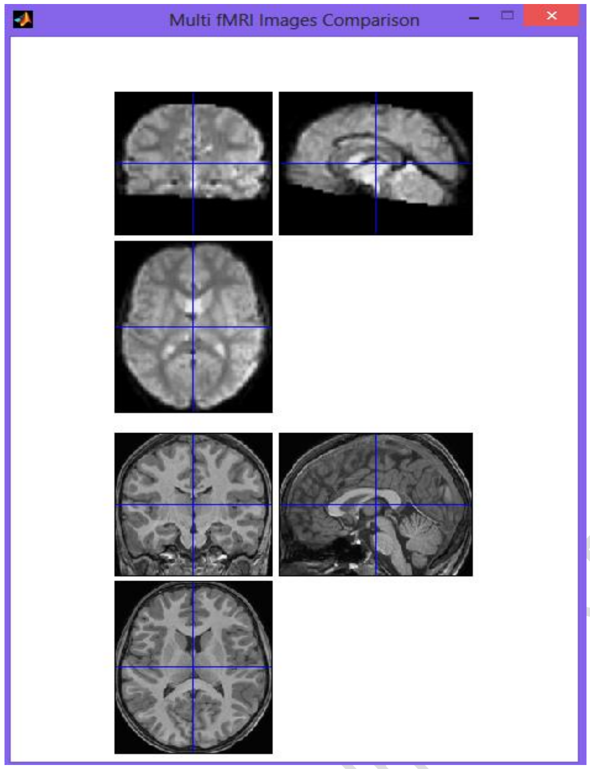

Figure 17 Display_ Multi_ Image comparison

4. CONCLUSION AND DISCUSSION

The proposed VCfMRI toolbox package designed and developed to address many of the problems when visualizing multi-format fMRI data. This toolbox is implemented under the MATLAB platform and 64-bit Windows environment for visualizing fMRI time series data. The integration of multi conversion processes of multi-format fMRI data is an essential and first step for preparing fMRI data for post-processing analysis, namely statistical analysis.
DICOM is an inconvenient format for fMRI data analysis. One problem is that a single fMRI session typically generates several thousand DICOM files. Furthermore, each of these files includes its header, even though all of these separate headers are mostly identical. Thus, a single fMRI session creates an enormous number of large DICOM files that contain much redundant information. All of these files make data analysis difficult, so the raw DICOM files often convert to any other more convenient format (like NIFTI and ANALYZE format) before data analysis begins.

The proposed VCfMRI package is an authoritative and straightforward tool to address numerous of the issues related to multi-format fMRI data, especially visualizing and conversion between all of these types of data. Therefore, the package provides the following main features:

1. Conversion tools of fMRI modalities
2. Converts fMRI raw data to a more friendly and straightforward format such as Analyze, NIFTI and .mat format
3. VCfMRI package can view diverse fMRI image formats, such as Analyze, NIFTI, .mat, and 4D
4. Create 2D fMRI data
5. Export images to MATLAB format
6. Reading/writing and viewing of all fMRI data formats
7. Visualizing 3-dimensional(sagittal, coronal and horizontal slices)
8. Reference and based tools, especially for physicians, healthcare specialists, and researchers who faced challenges about how handling with these type of data.
9. User-friendly for comprehensive neuroscience tools because contain all fMRI data formats (DICOM, ANALYZE, NIFTI, and MAT) conversion modalities.

In conclusion, the unique features of VCfMRI toolbox lie in its specific design for the direct handling of fMRI data conversion processes. Based on our experience and review of many works of studies on the fMRI data conversion, this work will be the first in the literature because there are no software packages contain all conversion processes like our toolbox. In VCfMRI package, 12 conversion processes of fMRI data format are performed as well as the ability to visualize all modalities of fMRI data format in one package.

The current proposed work is comprehensive, very necessary and has vital significance, especially for physicians in the neuroscience area, healthcare specialists, engineers, and researchers whose faced challenges about how handling with these type of data.

Ethical Considerations

Compliance with ethical guidelines

The research approved by the Local Ethics Committee of National Magnetic Resonance Research Center (UMRAM)-Bilkent University. Before participation in the study, informed written consent was taken from all participants.

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Conflict of interest

The authors declare no conflict of interest.

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REFERENCES

3D Slicer. (n.d.). Retrieved February 17, 2019, from https://www.slicer.org/

AnalyzeDirect : 3D Medical Image Analysis Software for Research. (n.d.). Retrieved February 17, 2019, from https://analyzedirect.com/

Ashburner, J. (2012). SPM: A history. *NeuroImage*, *62*(2), 791–800. https://doi.org/10.1016/j.neuroimage.2011.10.025

Ashby, F. G. (2014). Data Formats BT - Statistical analysis of fMRI data. *Statistical Analysis of FMRI Data*, 1–8. Retrieved from http://cognet.mit.edu/system/cogfiles/books/9780262295697/pdfs/9780262295697_chap2.pdf%0Apapers3://publication/uuid/A163C675-3808-4781-8CFA-9B06B7F34E3F

Behroozi M, Daliri M R, B. H. (2011). Statistical Analysis Methods for the fMRI Data. *Basic and Clinical Neuroscience*, *2*(4), 67–74. Retrieved from http://bcn.iums.ac.ir/article-1-181-en.pdf

Behroozi M, D. M. R. (2013). Software Tools for the Analysis of Functional Magnetic Resonance Imaging. *Basic and Clinical Neuroscience*, *3*(5), 71–83. Retrieved from http://bcn.iums.ac.ir/article-1-285-en.pdf

Bidgood, W. D., Horii, S. C., Prior, F. W., & Van Syckle, D. E. (1997). Understanding and Using DICOM, the Data Interchange Standard for Biomedical Imaging. *Journal of the American Medical Informatics Association*, *4*(3), 199–212. https://doi.org/10.1136/jamia.1997.0040199

BrainVoyager. (2012). Brain Innovation - Home. Retrieved from https://www.brainvoyager.com/

Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9–21. https://doi.org/10.1016/j.jneumeth.2003.10.009

Documentation — Neuroimaging Informatics Technology Initiative. (n.d.). Retrieved February 17, 2019, from https://nifti.nimh.nih.gov/nifti-1/documentation

Eloyan, A., Li, S., Muschelli, J., Pekar, J. J., Mostofsky, S. H., & Caffo, B. S. (2014). Analytic programming with fMRI data: A quick-start guide for statisticians using R. *PLoS ONE*, *9*(2). https://doi.org/10.1371/journal.pone.0089470

FIL Methods Group - Publications. (n.d.). Retrieved February 17, 2019, from https://www.fil.ion.ucl.ac.uk/spm/doc/biblio/

Filippi, M. (2009). *fMRI Techniques and Protocols* (Vol. 41). https://doi.org/10.1007/978-1-60327-919-2

Frackowiak, R., Friston, K., Frith, C., Dolan, R., & Mazziotta, J. (1997). Human brain function. *Academic Press*, *2nd*(2), 1144. https://doi.org/10.1016/B978-012264841-0/50057-3

FreeSurfer. (n.d.). Retrieved February 17, 2019, from http://surfer.nmr.mgh.harvard.edu/

FSL - FslWiki. (n.d.). Retrieved May 22, 2019, from https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/

FslView - FslWiki. (n.d.). Retrieved February 17, 2019, from https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/FslView

Graham, R. N. J., Perriss, R. W., & Scarsbrook, A. F. (2005). DICOM demystified: A review of digital file formats and their use in radiological practice. *Clinical Radiology*, *60*(11), 1133–1140. https://doi.org/10.1016/j.crad.2005.07.003

Jenkinson, M., Beckmann, C. F., Behrens, T. E. J., Woolrich, M. W., & Smith, S. M. (2012). Fsl. *NeuroImage*, *62*(2), 782–790. https://doi.org/10.1016/j.neuroimage.2011.09.015

Larobina, M., & Murino, L. (2014). Medical image file formats. *Journal of Digital Imaging*, *27*(2), 200–206. https://doi.org/10.1007/s10278-013-9657-9

Li, X., Morgan, P. S., Ashburner, J., Smith, J., & Rorden, C. (2016). The first step for neuroimaging data analysis: DICOM to NIfTI conversion. *Journal of Neuroscience Methods*. https://doi.org/10.1016/j.jneumeth.2016.03.001

Liu, Z., Kecman, F., & He, B. (2006). Effects of fMRI-EEG mismatches in cortical current density estimation integrating fMRI and EEG: A simulation study. *Clinical Neurophysiology*, *117*(7), 1610–1622. https://doi.org/10.1016/j.clinph.2006.03.031

McDonald, C. R. (2008). The use of neuroimaging to study behavior in patients with epilepsy. *Epilepsy and Behavior*, *12*(4), 600–611. https://doi.org/10.1016/j.yebeh.2007.10.016

Mildenberger, P., Eichelberg, M., & Martin, E. (2002). Introduction to the DICOM standard. *European Radiology*, *12*(4), 920–927. https://doi.org/10.1007/s003300101100

MRIcron Index Page. (n.d.). Retrieved February 17, 2019, from http://people.cas.sc.edu/rorden/mricron/index.html

NITRC: NIfTI: Tool/Resource Info. (n.d.). Retrieved February 17, 2019, from https://www.nitrc.org/projects/nifti/

NITRC: NUTMEG: Tool/Resource Info. (n.d.). Retrieved February 16, 2019, from https://www.nitrc.org/projects/nutmeg/

Oostenveld, R., Fries, P., Maris, E., & Schoffelen, J.-M. (2011). FieldTrip: Open Source Software for Advanced Analysis of MEG, EEG, and Invasive Electrophysiological Data. *Computational Intelligence and Neuroscience*, *2011*, 1–9. https://doi.org/10.1155/2011/156869

Orden, V. (2006). What Has Functional Neuroimaging Told Us About the Mind (So Far)? *Cortex*, *42*, 323–331.

Robb, R. A., Hanson, D. P., Karwoski, R. A., Larson, A. G., Workman, E. L., & Stacy, M. C. (1989). Analyze: A Comprehensive, operator-interactive software package for multidimensional medical image display and analysis. *Computerized Medical Imaging and Graphics*, *13*(6), 433–454. https://doi.org/10.1016/0895-6111(89)90285-1

S.M., S., & B.R., R. (2007). Mapping Cognitive Function. *Neuroimaging Clinics of North America*, *17*(4), 469–484. https://doi.org/10.1016/j.nic.2007.07.005

Teo, P. C., Sapiro, G., & Wandell, B. A. (1997). Creating connected representations of cortical gray matter for functional MRI visualization. *IEEE Transactions on Medical Imaging*, *16*(6), 852–863. https://doi.org/10.1109/42.650881

Whitcher, B., Schmid, V. J., & Thornton, A. (2011). Working with the DICOM and NIfTI Data Standards in *R*. *Journal of Statistical Software*, *44*(6). https://doi.org/10.18637/jss.v044.i06