MULRECON: A Web-based Imaging Viewer for Visualization of Volumetric Images

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Recent developments in web technology allow pixel-level manipulation of radiologic images. This paper presents an easily accessible imaging viewer for visualization of volumetric datasets which leverages modern web technology. The viewer is designed to enable on-the-fly multiplanar reconstructions with different projectional techniques, and these can be manipulated as in a Picture Archiving and Communication System. The application opens up possibilities for teaching and demonstrational purposes. Step-by-step instructions for how to use are provided and the source code is made available.

Background

Contemporary medical practice increasingly relies on diagnostic imaging to support clinical diagnoses, and to optimize patient pathways. Consequently, physicians in all subspecialities need to acquire radiological knowledge and skills,[1] and as part of modern radiological education, there is a demand for interactive web-based teaching tools.[2] Moreover, the development in the workflow of medical imaging has seen a transition from a single slice paradigm to navigation of 3-dimensional datasets using image manipulation and processing tools such as on-the-fly multiplanar reconstruction with different projectional techniques.[3,4] Previous studies have reported that the cognitive processes needed to evaluate volumetric imaging studies are different from evaluating 2-dimensional images.[5] Although there are a number of stand-alone software tools available for teaching and demonstrational purposes that allow familiarization with the process of contemporary medical imaging interpretation, there is a paucity of easy accessible web-based applications with features mentioned above.

A web-based imaging viewer, dubbed Mulrecon, with radiology workstation-like features was developed to fill this gap. This manuscript describes the development and functionality of this web-based application. A step-by-step guide with sample image stacks is also provided.

Material and Methods

Mulrecon was implemented as a device-independent web application using JavaScript and HTML5. The frameworks JQuery UI, jQuery UI Touch Punch, and dicomParser.js were used for user interface,

touch functionality, and DICOM (Digital Imaging and Communications in Medicine) support, respectively. JavaScript Webworkers was deployed for processing of multiple threads thereby exploiting multiple cores of the central processing unit (CPU), allowing the user interface to remain responsive while performing rendering.[6] In brief, Mulrecon generates multiplanar reconstructions by loading a stack of DICOM or JPEG images from a given study, and thus a matrix of voxels is established. Combined with the information provided by DICOM tags, arbitrary (oblique) 2D slices can be generated. Oblique slices are defined by a position vector inside the volume dataset and the normal vector of the plane. The voxels on the intersection of the volume dataset and the 2D slice in question are the visual representation of the oblique slice. A trilinear interpolation algorithm is used for smooth reconstructions.[7] Mulrecon was tested on desktop and mobile platforms (with touchscreen support) engaging the most widely used internet browsers.

Results

The result is a web-based application that allows manipulation and interpretation of cross-sectional imaging studies mirroring radiological practice. As an example, having only a single-axial CT series available, both sagittal and coronal series may be generated, as well as other arbitrary orientations.

Full functionality was achieved with the tested internet browsers on desktop and mobile platforms (Table 1). While Mulrecon does not need to be installed, the user has to go through a number of steps to either specify a folder or manually select local files to be loaded into Mulrecon (Table 2, Fig 1).

Once either of these steps has been completed, a user is presented with a browser-based Picture Archiving and Communication System (PACS)-like interface. The top menu contains basic tools as seen in a typical PACS. By default, 3 image stacks with conventional radiological orthogonal slices are presented: coronal, axial, and sagittal from left to right with each stack displaying

TABLE 1
Mulrecon browser compatibility

Internet browser	PC*	MAC[†]	Android[‡]	iOS[§]
Chrome	X	X	X	X
Firefox	X	X	X	X
Safari	X	X	X	X
Edge	X	X	X	X

*Windows 10.
[†]macOS 10.13 High Sierra.
[‡]Oreo 8.1.
[§]iOS 11.

cross-reference lines (Fig 2). To further facilitate orientation, a cuboid superimposed on another cuboid is shown in the top left corner. The former cuboid with small colored spheres, corresponding to the borders of the generated image stacks, represents the orientations and slice positions of the image stacks in relation to the source axial image stack.

The stacks can be manipulated in several ways (Table 3).

A key feature is *Rotation* which facilitates generation of planes in any desired orientation and these may be thickened into slabs using the projectional techniques of average, maximum, and minimum intensity projections (Fig 3).

Additionally, when using the *Specify folder option*, the button *Get URL* will generate a uniform resource locator (URL) with a query string based on the previous input parameters. Subsequently, the application can be opened with just this URL and does not require any initial user input. A table of contents of imaging studies can be generated referencing URLs with different query strings. An example table of contents can be found at the project website.

Furthermore, although Mulrecon can handle typical image stacks of resolution 512×512 pixels on even low-end PCs, performing thick slab reconstructions may result in a significant decrease in speed. As not all users have the same hardware or preferences for speed versus detail, the stack resolution can be altered through the *Quality* option in the toolbar menu.

Finally, for those who are merely interested in a swift visualization of a cross-sectional study in a web browser which can be shared, a version of Mulrecon connected to a webserver has been constructed. This version has a file chooser that allows users to upload an image stack in a zip file where the image files do not need to be named

alphanumerically, as previously described in Table 2. Subsequently an uploaded image stack can be shared using *Get URL*.

Discussion

The developed web application has multiple applicabilities as it can be placed in a local folder or on a webserver. A local folder could be a USB key, which would enable the creation of a highly portable collection of private teaching cases. With the webserver option, a list of cases can be shared online with a broad audience. Moreover, the application could facilitate supplementary interactive visualization of imaging results for readers of medical journal publications as many articles are published online. As regards teaching files, it has previously been described how PowerPoint software (Microsoft, Redmond, WA) can be used to create interactive presentations.[8] Since PowerPoint allows inclusion of web hyperlinks, Mulrecon could supplement a PowerPoint-based teaching file with PACS-like functionalities.

For those with web programming skills, more advanced teaching files can relatively easily be generated by expanding the application with a dialogue widget containing case information.[6]

Mulrecon offers several advantages. It utilizes HTML5 which allows cross-platform compatibility and pixel-level image processing without relying on third-party browser plug-ins (eg, Flash and Java Applets) which potentially pose a security risk.[6]

Prior web-based viewers (slicedrop.com being a notable example) have implemented basic *orthogonal* multiplanar reconstruction. However, in contrast to previously published web-based methods, Mulrecon allows generation of *double oblique* reconstructions with different projectional techniques as well as varying of slice thickness. Furthermore, the option to use compressed JPEG images is an advantage when curating teaching files as it is common for JPEG's lossy algorithms to achieve 10:1 compression (the DICOM file is 10 times the size of the compressed file) without substantial loss in image quality with JPEG, and the same time ensuring patient confidentiality by avoiding DICOM metadata.

Mulrecon has some limitations. The *Specify folder* option is available only with JPEG files. In addition, when using Mulrecon for PowerPoint, image files are not saved in the PowerPoint file itself. It is also a limitation that the use of pure JavaScript for image rendering mainly utilizes the CPU of the device running the application.

Future development tasks include meeting the limitations above, especially regarding increasing the speed of the application by using graphics processing unit (GPU)-accelerated JavaScript.

In conclusion, an on-demand platform-independent web applica-

TABLE 2
Instructions for loading image stacks into Mulrecon

Step	Specify folder	Manually select files
1	Get the files for Mulrecon which are freely available for download at the author's website in zip format. The contents of this zip file must be unpacked and placed in a dedicated application folder either on a local computer* or uploaded to a webserver depending on whether files should be publically accessible.	
2	On opening the file sprayMPR.html with an internet browser, the user is prompted to select either *DICOM files* or *JPEG* files[†].	
3	Place a stack of JPEG images in a single folder in the same folder as where the web application is placed. The images must be named *axial* followed by sequential numbering with or without leading zeros, that is, axial00001.jpg, axial00002.jpg, axial00003.jpg...axial00014.jpg, etc. or axial1.jpg, axial2.jpg, axial3.jpg, etc.	JPEG files: The user is prompted to input the following 4 parameters: DICOM tags of *pixel spacing, slice thickness, spacing between slices*, and stack plane (ie, axial, coronal or sagittal; Fig 1).
4	The user is prompted to input the following 6 parameters: name of folder to load from, number of images and the DICOM tags of *pixel spacing, slice thickness, spacing between slices*, and stack plane (ie, axial, coronal, or sagittal) (Fig 1).	JPEG files: Select the JPEG files of an image stack placed in a local folder. DICOM files: Select the DICOM files of an image stack placed in a local folder.

*Due to Webworker restrictions running Mulrecon with *Specify folder* from a local folder is currently only available with the Firefox, Edge, and Safari browsers.
[†]Most PACS systems provide the means for exporting DICOM images to anonymized Health Insurance Portability and Accountability Act compliant JPEG format and obtaining the DICOM tags needed as previously described.[9]
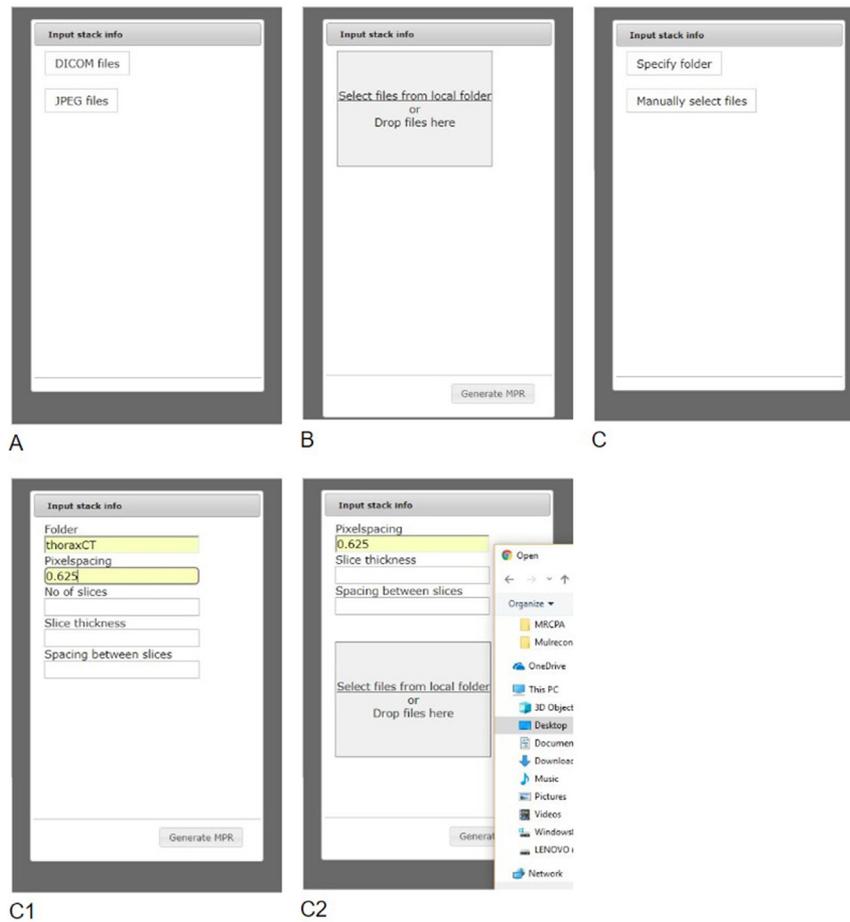
FIG 1. Screen captures of loading of image stacks.
A: *DICOM* or *JPEG* files option
B: *DICOM files*
C: *JPEG files; Specify folder* or *Manually select files*
C1: *Specify folder* (JPEG)
C2: *Manually select files* (JPEG).

FIG 2. Screen capture of the Mulrecon interface with a stack of brain MRI JPEG images as input. The interface consists of a top-middle menu and a top-left cuboid for multiplanar reconstruction orientation. In the bottom, the 3 orthogonal image stacks with cross-references lines.

TABLE 3
List of Mulrecon functionalities

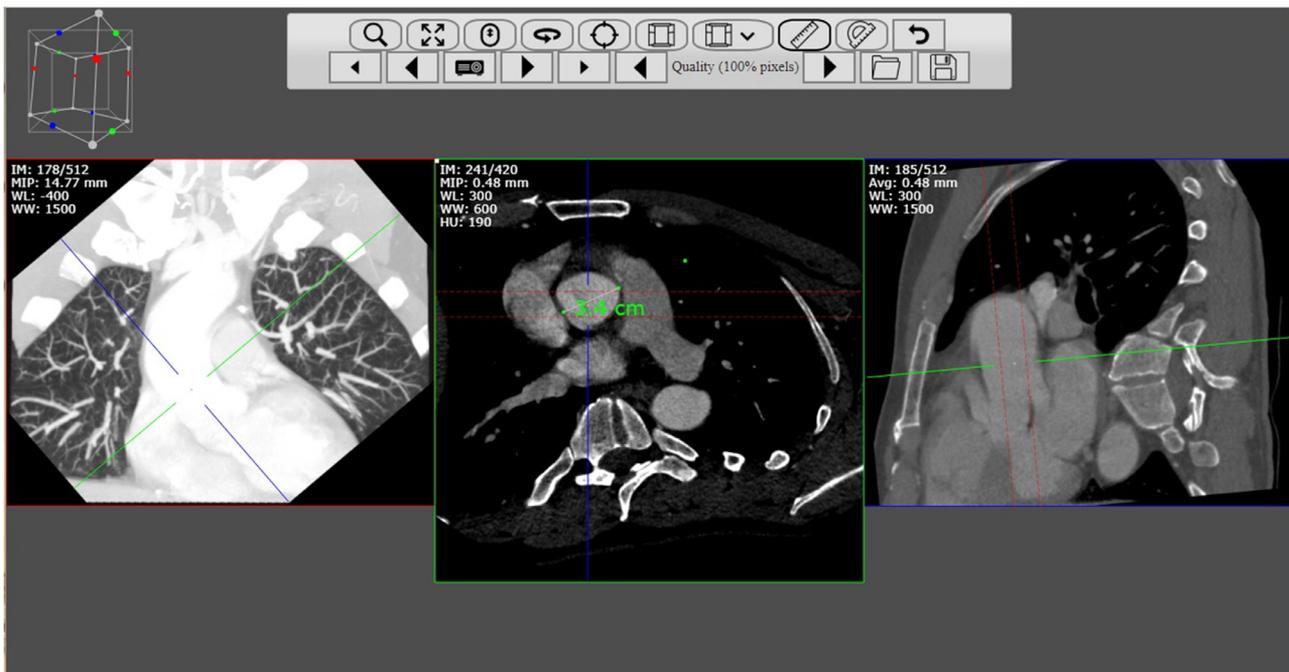| Function |
| --- |
| Pan |
| Zoom |
| Scroll |
| Synchronize |
| Caliper, polygon, and angle tool |
| Slice thickness alteration |
| Projection technique (MPR, MIP, MinIP) |
| Rotation |
| Save images |
| Window/level alteration (DICOM files only) |
| Brightness and contrast alteration (JPEG files only) |

FIG 3. Screen capture of the Mulrecon interface with a stack of thorax CT DICOM images as input. Double oblique multiplanar reconstructions have been rendered with measurement of ascending aortic diameter. Thick slab MIP is rendered in lung window as well.

tion was developed for generation of multiplanar reconstruction from a stack of axial images that can be manipulated as in a PACS. As Mulrecon is open-source software, the version 1.0 source code is available on the project website (http://www.castlemountain.dk/atlas/index2.php?page=mulrecon).

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