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A Web-based Image Viewer for Multiple PET-CT Follow-Up Studies

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***Abstract* — There exist many viewers for single-modal medical images that are efficient and are equipped with powerful analysis tools. However, there is a distinct lack of efficient image viewers for multi-modality images, particularly for displaying multiple follow-up studies that depict a patient's response to treatment over time. Such viewers would be required to display large amounts of image data. In this study, we present the TAGIGEN viewer – a web-based image viewer designed specifically for the visualisation of multi-modality follow-up studies. We innovate by defining a series of dynamically generated image grid layouts that display sets of related images together in order to improve the ability to compare and assimilate the myriad images. We adopted a web-based client-server image streaming technology, thus enabling interactive navigation of the images in a computationally efficient manner. Furthermore, our web-based approach is interoperable and requires no software installation. We evaluated the ability of our viewer in displaying and understanding a patient's follow-up images in a case study with combined positron emission tomography and computed tomography (PET-CT) follow-up scans. We conducted a usability survey on 10 participants to measure the usefulness of our viewer, used as an outpatient viewer e.g. viewer designed for use by the patients, in tracking a patient's disease state across four PET-CT studies. Our initial results suggest that our viewer was able to efficiently visualise the patient data over time, and that the web-based implementation was fast (loading on average within 5.6 seconds with real-time navigation) and easy to use (overall survey score higher than 4 / 5).**

***Index Terms*—Web-based viewer; Multi-modality imaging; PET-CT; Follow-up scans; Response to treatment.**

I. Introduction

MEDICAL imaging plays a vital role in modern healthcare as almost every clinical discipline utilises it to a certain extent. This has resulted in an explosive growth in the amount of imaging acquisitions and also in the development of new imaging modalities, such as combined positron emission tomography and computed tomography (PET-CT), which captures both functional (PET) and structural (CT) images sequentially on one scanner. PET-CT is rapidly becoming the preferred imaging modality for the diagnosis of cancer and the assessment of treatment response [1,2]. However, the images produced by these scanners are very large, which introduces challenges in the assimilation and visualisation of these images. Moreover, follow-up scans that are acquired to assess the patient's response to treatment further exacerbate the massive amount of image data (in excess of several thousand slices).

There are many non-commercial and commercial medical image viewers currently available, such as OsiriX [3], Syngo (Siemens) [4], ImageJ [5] and ITK-based variants such as MEDINRIA [6] and 3D Slicer [7]. Each of these viewers is designed for specific purposes. For example, Syngo is a commercial product designed for diagnosis and is equipped with sophisticated tools and features, whereas ImageJ and the ITK-based viewers are geared more towards research and education. Another category of viewers are those optimised for outpatients and referrers such as the viewers provided by Codonix [8] and MedView [9]. However, these viewers are typically limited to handling a single patient scan and are often restricted in their ability to interactively display multiple scans simultaneously. Another limitation is the time-consuming process of loading the large images before the viewer can be used.

A number of web-based image viewers that provide flexible user interfaces and easy navigation to browse through large image gallery have recently become available. Cooliris [10], TiltViewer [11] and HighSlide [12], built using Flash, Java or .NET web technologies, respectively, are examples of such viewers. These image gallery based viewers typically place thumbnails on a grid layout in a way that allows multiple images to be visualised simultaneously. This is especially useful when a user needs to find or discover items, and has been shown to improve human-computer interaction in image and video annotation, and in media browsing [13-15]. Furthermore, these web-based viewers stream images as they are being viewed and as such do not have long loading times.

In this study, we propose the TAGIGEN viewer – an image viewer optimised for the visualisation of multiple follow-up scans of multi-modality PET-CT images. Our viewer enables interactive visualisation of changes (response to treatment) over time (scans) in an efficient and intuitive user interface that provides the means to compare and assimilate large amounts of image data simultaneously. Our viewer is based on

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client-server image streaming and thus enables real-time interactive navigation of the images without pre-loading them. For this purpose we adopted Cooliris, a leading image viewer in terms of speed, due to its ability to enable rapid visualisation of large image galleries in a customisable grid-layout configuration via client-server image streaming [10]. Our web-based approach is also interoperable and requires no software installation.

II. METHODS

A. System Architecture and Design

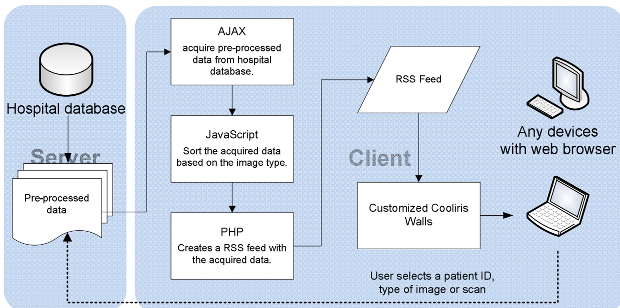

Fig. 1. An overview of our system.

The overall architecture of our design is shown in Fig. 1. The system is divided into two parts – the *client*, which contains the web-based viewer; and the *hospital* server where patient data is stored. For each patient set, a unique URL is generated. Loading a URL in a web browser accesses a webpage that contains the TAGIGEN and initiates the transmission of pre-processed images from the server to the client. The details of these processes are explained in the following sections.

B. Data Collection and Pre-processing

Whole-body PET-CT scans were obtained on a Siemens Biograph TruePoint scanner at the Department of PET and Nuclear Medicine, Royal Prince Alfred Hospital. The PET and CT images were rescaled to equal dimensions of 256×256 pixels at 1.982mm^2, with a slice thickness of 3.0mm. We also collected the physician's reports associated with the scans.

We used the Elastix registration package [16] to compute the transform $T_{1\leftarrow I}$, which represents the parameters that warp the i^{th} image I^i to the space of the initial PET-CT scan I^1. Affine followed by non-rigid B-spline registration algorithms were used to automatically transform the CT pairs. The resulting transforms were then used to register the PET counterparts. The CT image was used in initial the registration due to its better anatomical definition and higher resolution compared to its PET counterpart [17]. The average reverse transform from one slice was used to find the approximate corresponding slice in another study. This allowed us to map anatomical locations approximately across time.

The rescaled PET-CT images were automatically formatted into multi-planar views of coronal PET, sagittal PET and coronal fused PET-CT views. These views were selected based on the preferences in our hospital environment; alternate views, such as the axial slices and CT counterparts, may also be selected. These selected images were then converted into a lossless JPEG format.

C. TAGIGEN Viewer Design

The pre-processed images were used to generate an RSS web feed [18] containing the image's slice number and its physical location on the web server. The RSS is generated using PHP and JavaScript utilities. The RSS feed supplies Cooliris with URLS to the images that are to be streamed into a web browser. Upon user input, the viewer changes its display content by rewriting this RSS feed dynamically.

Fig. 2 depicts the main user interface (UI) components of the TAGIGEN viewer with a sample patient study. The left panel consists of three rows of images; each row is a slice sequence of a particular scan i.e. each row displays slice $1,2\ldots N$, where N is the total number of slices. The middle row is the primary row and contains the scan selected by the user at time t_n , the top row contains scans from time t_{n-1} and the bottom row from t_{n+1}. All the scans are aligned. We adopted a grid-layout view where the rows represent the time (scan) and the columns represent the slice sequence. Using our layout, a user can immediately visualise the current scan t_n in relation to its previous and follow-up scans, if available, thus providing a visual indication of the changes in the images.

This interface is controlled with a mouse or a touch pad. The images in a row can be navigated by dragging the mouse across the particular row, which triggers the streaming of new images from the server. This dragging action also changes the image slices in the other rows. Clicking an image causes it to be centered and slightly zoomed to emphasise the selection, as shown in Fig. 2. The scroll wheel on a mouse can be used for zooming in and out of the selected image.

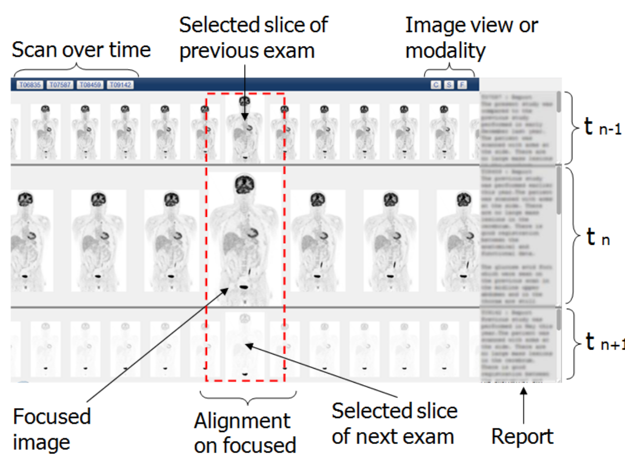

Fig. 2. The TAGIGEN viewer with a sample PET-CT patient study. Each row represents a image scan from a scan sequence. The middle row displays the user selected scan, and the upper and lower rows present the previous and the next scan, respectively. The images in the rows are aligned. The patient report panel on the right has been blurred for privacy.

The '*scan over time'* buttons on the upper-left corner allow the selection of other scans available in the patient study; the selected scan becomes the t_n scan. Interacting with the '*image view or modality*' buttons on the top-right corner accesses the

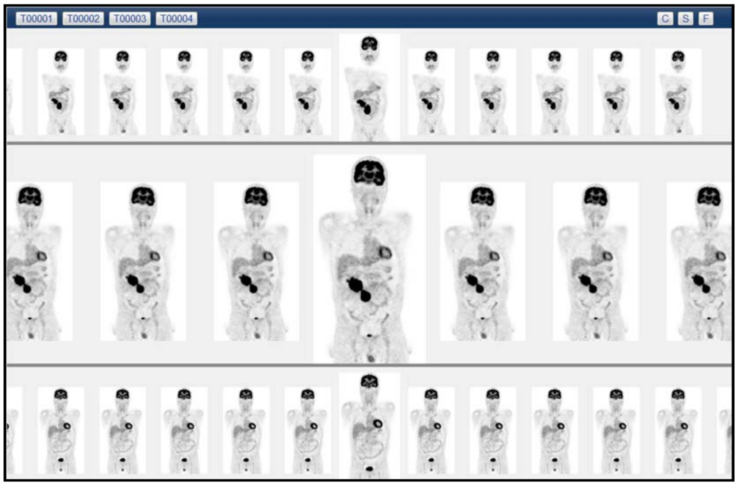

Fig. 3. The TAGIGEN viewer. An example of a patient study with four aligned follow-up scans. In this example, the changes in the tumour from three follow-up scans (top to bottom rows) are clearly visible as dark spots in the abdomen area. A user-selection of an image on the middle panel triggers magnifies the image (in this case by a factor of 1.4) and aligns the upper (previous scan) and lower (following scan) image sequences.

multi-planar views. The focus on the selected slice is retained with the changes in the scan and the views e.g. a change from coronal to sagittal view will keep the current slice centered and zoomed after the images have been coronal images have been replaced with sagittal slices. The panel on the right displays the patient reports corresponding to the scans that are currently displayed. The placement of the report next to the scans provides a quick reference to the physician's diagnosis.

III. RESULTS

A. *TAGIGEN Viewer*

Fig. 3 depicts our TAGIGEN viewer displaying images of a patient who has been diagnosed with lymphoma. Three follow-up scans in addition to the original scan were conducted to study the patient's response to treatment. Our pre-processing automatically aligned all four scans. Thus, the image rows are vertically aligned and show the response to treatment over time. The viewer was hosted on an Intranet.

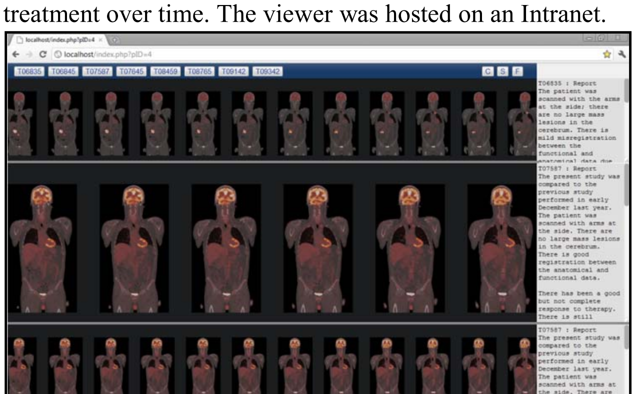

Fig. 4. TAGIGEN viewer showing three follow-up scans (from a total of eight) of a patient study. The coronal fused PET-CT view is displayed.

In this example, the dark spots in the upper row (tumors) were reduced in the two following scans (indicating that the tumours responded positively to treatment). The images were navigated in real-time by dragging the images from side-to-side in the middle row. This caused the images in the upper and lower row to move in synchronicity. The ability to navigate through the three scans simultaneously enabled efficient tracking of the tumour. Selecting a different scan immediately triggered the new scan to be loaded into the viewer without any noticeable lag.

Fig. 4 depicts another example of our viewer in operation, displaying fused PET-CT images across three follow-up scans within the Google Chrome web-browser. This particular patient has a total of eight scans as indicated by the buttons in the top-left corner.

B. *Computational Performance*

We evaluated the interactive performance of our TAGIGEN viewer by simulating a typical usage scenario (see Sect. C below). We measured the time to load images from the server, based on the selection of different patients, who had either three or four PET-CT image sequences. We also evaluated the interactive performance of the system during image navigation. There were in excess of 400 individual image slices for a typical three-scan sequence. A consumer PC with Intel Core2 Quad Q6600 @ 2.4Ghz; 4G RAM; 64bit Windows7 OS was used as the test system. We used Google Chrome as the test web browser. The image sequences were loaded within an average time of 5.6 seconds (standard deviation of 1.5*s*) over 10 cases. Once loaded, during image navigation the images were streamed in real-time with no noticeable lag. The peak RAM usage was ~34% and the peak CPU was 47.4%. These values, gathered when the server was set as a local host, suggest that our viewer can be used sufficiently in a standard consumer PC. Our viewer is not restricted to any particular browser or operating system. We also tested our viewer with Internet Explorer, and with Firefox under MacOS, with all configurations resulting in comparative performances.

C. *User Case Study*

We ran a controlled user trial in order to measure the usability of our viewer in displaying and helping humans understand medical images. This trial included 10 participants (all ICT students) familiar with web-based image browsing and navigation. Eight of the ten students were familiar with PET-CT imaging. We conducted repeated experiments using a test scenario where the participants would view the initial PET-CT scan and the three follow-up PET-CT studies to identify changes that occurred as the patient underwent cancer treatment. Two variables were measured: (i) Task completion success rate, and (ii) User satisfaction on using the viewer to complete the task. We devised a survey based on IBM post-study questionnaire framework [19]. Ten questions were designed to measure the proposed viewer's usefulness based on a 5-point scale, anchored at the end points with the terms 'strongly agree' and 'strongly disagree'. Comment spaces were available for each question.

The participants were trained to use our viewer with a simple introductory manual, which exemplified the usage of the viewer and provided a brief introduction to PET-CT imaging. Assistance was available if required only for clarifying medical terms relating to PET-CT imaging that appeared in the patient reports. All participants had no prior exposure to the viewer. After this brief introduction, the participants were then further instructed on the use of the system in a specific scenario. Their task was to identify the non-small cell lung cancer (NSCLC) tumour clearly visible on the initial scan (t_0) following the description in the patient report, and tracking the tumour as it evolved during the treatment. The tumour was visible in second (t_1) and third (t_3) scans but disappeared from view in the fourth scan (t_4). The participants were asked to read the diagnostic report and then correlate the findings in the report to the visual features in the images i.e. identify the tumour and track its response over time in corresponding follow-up scans.

We calculated statistics from the survey and the outcomes are summarised as follows. All participants were successful in completing the task. We observed that the major difficulty of the task was in understanding the layout of the viewer (average rating of 3.6/5). Based on the comments, we attribute this rating to the amount of information that was shown at once (see Fig. 4), as well as the limited on-screen help/instructions. The minimalistic approach to our UI design to save screen space was found to cause confusion among the participants. Another difficulty the participants faced was in relating structures described in the reports to regions within the images (4.4). This prompted 4 participants to seek assistance. As expected, the 2 participants with no experience in medical imaging had a more difficult time in understanding the report and correlating it to the images. The participants were positive in the viewer's ability to view the follow-up scans (4.9), which was the core requirement for this task. Speed and interactivity were also rated as useful features (4.8 and 4.7, respectively).

IV. CONCLUSION AND FUTURE WORKS

The TAGIGEN viewer is an interactive web-based application that lets users explore multi-modality follow-up scans. Using our proposed grid layout, the users are able to comparatively visualize large numbers of images simultaneously and interactively. We demonstrated the efficiency of our viewer in terms of loading time, RAM and CPU usage on a consumer PC. Our survey suggests that that the viewer was an effective tool for exploring multiple follow-up scans of PET-CT images.

In our future research, we will focus on improving our design by adding more interactive functions such as anatomical region cues overlaid on the images and other methods of providing feedback to assist the user in interpreting the images. We will expand our evaluation to other user scenarios e.g. referring physicians.

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