Virtual Slide Telepathology Systems with JPEG2000

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ABSTRACT

In the present paper we analyze the JPEG2000 standard and how to exploit all the offered powerful features to build efficient telepathology systems based on virtual slides. We also propose a fast method for stitching in the wavelet domain. Stitching is a process necessary in many virtual slide systems to generate only one image of a slide with the maximum resolution. This method profits from the structure of the JPEG2000 images to carry out the process with the minimum memory consumption and computational load, obtaining a smoothed union without losing any detail.

INTRODUCTION

Telepathology is the practice of the pathology at distance. A pathologist can make diagnostics by observing through a communication link the medical slides captured by a remote microscope. This way the localization of the pathologist and the medical slides are unbound. So for example, diagnostics of different pathologists from different centers can be compared and shared.

There are different kinds of telepathology systems, all of them commented in [1]. The first generation of these systems consists in the acquisition of the microscope image, either in real-time mode or in store-and-forward mode, and its sending to the pathologist. This can remotely manipulate the microscope to select the slide region to visualize, requiring a new acquisition whenever this region changes. In these systems the operator is always bound to the microscope, so any session requires to use in an exclusive way this device. Its use of the device is clearly inefficient and redundant.

The second generation of telepathology systems introduces the concept of virtual slide. Virtual slides are digitizations of entire slides, that are stored in a server for its later remotely inspection. A client/server architecture allows pathologists to navigate remotely through the virtual slides, simulating the working of a microscope. Different regions of the virtual slide can be observed, allowing to increase o decrease the zoom, without having to download the entire remote image. The server sends only the required data to see. Pathologists have in this way the sensation of working with a virtual remote microscope, with the difference that, in this case, the digitization is made in a previous step, of the whole slide. It is not necessary to reuse the microscope for the same slide. In [2] it is proposed a possible implementation of a system with these characteristics.

To obtain a digitization of the entire slide with the enough quality for a correct diagnostic, it must have, among other features, the appropriate resolution. Complying this premise is not always possible with the available acquisition device. In many cases its resolution is not enough to cover the entire slide in order to digitize without losing detail. In these cases the slide is divided in contiguous regions in order that each region is digitized with the maximum resolution of the device. In a posterior step all the resulting images are joined in a stitching process, generating only one big image with the necessary detail.

The JPEG2000 still image compression standard is being imposed bit by bit in the context of imaging medical systems, due to its powerful features. Telepathology systems are being favoured with the characteristics of this standard . The quality of the image compressed with JPEG2000 for the same bit-rate is quite higher than that offered by its predecessor, the JPEG standard, as it can been observed in [3]. This feature is essential in systems based on virtual slides, due to the images usually have a very big size, requiring the maximum compression ratio but losing the minimum quality.

JPEG2000 offers a high scalability, allowing a random access to the compressed bit-stream of the image, as well as its transmission by means of a quality progression. These features are specially interesting in the virtual slides context, allowing the server to extract regions of the images without recodification, and sending them adapting the communication to the available bandwidth. The JPIP protocol is defined within the same standard, designed to exploit at the maximum the features of this compression standard in remote browsing applications, as for example, telepathology virtual slide systems.

In the present paper the main features of the JPEG2000 standard are analyzed, as well as the JPIP protocol, showing how they can be used to build efficient telepathology virtual slide systems. It is also proposed a fast and simple method to construct virtual slides based on the stitching in the domain of the wavelet transform, profiting that JPEG2000 uses this transform. With this method the necessary time and memory for the process are considerably reduced. Moreover, the image boundaries of the final montage appears quite smoothed without any additional processing or quality lost.

JPEG2000 FOR VIRTUAL SLIDES

JPEG2000 is the last ISO/ITU-T standard for still image coding. Some features of this standard are error-resilience, arbitrary region of interest coding, random access to the compressed stream, quality scalability and support for multiple components. These characteristics make it ideal for the coding and remote retrieving of large images.

JPEG2000 is based on the dyadic DWT (Discrete Wavelet Transform). Fig. 1 shows how the DWT decomposes an image in $1 + 3D$ spatial frequency subbands, where D is the number of analysis transform stages. The stage d generates four subbands LL_d, HL_d, LH_d and HH_d. L stands for the low-pass filter and H for the high-pass filter, and its position is associated to the direction of the filter (left when horizontally and right when vertically). Each stage d is applied to the LL_{d-1} subband, or the entire image when $d = 0$. As it can be observed, applying D analysis stages a multiresolution representation of the image is generated, with $D + 1$ different levels. Using the subbands LL_r, HL_r, LH_r and HH_r, the resolution level r can be reconstructed.

Each subband is divided into rectangular blocks called code-blocks which are independently coded and compressed. Code-blocks are collected in larger rectangular groups called precincts. The size of the code-blocks and the precincts determines the granularity for a later access to the compressed stream.

The compression process generates a list of concatenated packets. A packet includes an incremental contribution of all the code-blocks of a precinct. For each precinct there are as many packets as quality layers defined when compressing. The number of quality layers determines the scalability in quality.

The standard is organized in several parts. Part 1 [4] describes the compression system and how to build the simplest code-stream. This code-stream contains the packets generated by the image compression process and additional information. The simplest JPEG2000 image file format contains a code-stream, without any other addition. In this Part of the standard a more complex image file format is also defined, allowing to include any user metadata information. This is specially exploitable in telepathology systems. For example, in [5] it is proposed to include patient XML data within the same image file of the digitalized slide.

Part 9 [6] covers the definition of a new protocol, JPIP (JPeg2000 Interactive Protocol), as well as a framework to develop systems for remote browsing of JPEG2000 images. Fig. 2 shows a representation of the client/server structure proposed for this new protocol.

On the client side, the user specifies a

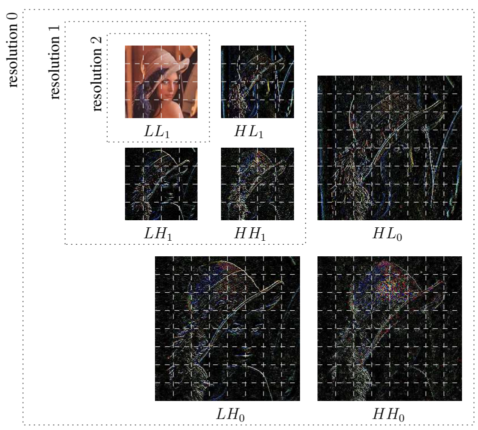

Figure 1: 2 DWT stages (3 resolution levels) applied to the *Lena* image, partitioned by code-blocks.

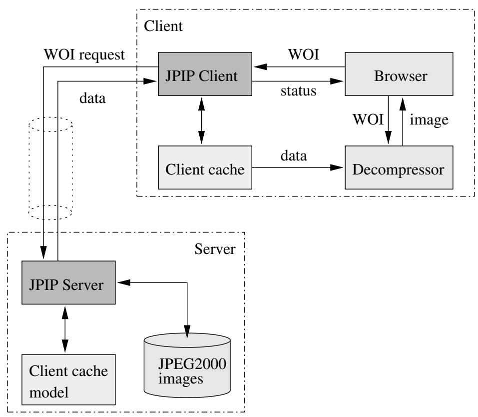

Figure 2: Client/server structure proposed for the JPIP protocol.

WOI (Window Of Interest) using the application browser. The WOI defines the region of the remote image that the user wants to see. This WOI is passed to the JPIP client module and the decompressor module. The first one manages the communication with the server, elaborating the corresponding request and reading the response from the server. When the information is read, it is stored in the internal cache. The decompressor module will gather the required cache information to reconstruct the WOI image, which will be shown to the user by the browser module. When the JPIP server receives a client request for a specific WOI, it reads the associated image extracting the appropriate information which must be sent to the client in order to reconstruct the requested WOI. Thanks to the high scalability offered by JPEG2000, this extraction can be done with a minimum of computational load. The server optionally maintains a model of the client cache, that is used to avoid resending redundant information to the client.

All the commented features offered by the JPEG2000 standard allow to build highly efficient telepathology systems based on virtual slides. All the images would be compressed with this standard. The image files can be used independently, without being included within any other more complex file. As advantage it is possible to include any associated metada, as it is proposed in [5], and retrieve it with any common JPIP client, independently of the metadata format. The compression of the images would be done in order to obtain a good scalability, configuring a large number of quality layers and a small size for precincts. In this way the server can extract more exactly only the required data and send it adapting the communication to the existent bandwidth. The pathologist can inspect remotely the images using a JPIP client, so all the architecture simulates a perfect virtual microscope.

STITCHING IN THE DWT DOMAIN

In the previous Section it has been possible to observe that the JPEG2000 standard offers all the necessary features to create telepathology systems based on virtual slides, and furthermore these systems can achieve a high efficiency. There is also other aspect in the context of the virtual slides that can be considerably improved using JPEG2000: the stitching of images.

Virtual slides are created as a composition of a set of microscope images that contain information about contiguous areas of an entire slide. This composition or stitching consists basically in three global steps: i) unification, ii) search of the matching regions, and iii) union. In the first step the possible geometric distortion of the images is corrected in order to be able to join all the images in the same plane. The possible differences of illumination between images, like for example the vignetting, are also corrected. In the second step the existent common regions between the images are searched, determining how to join them. Finally, in the last step, all the images are stitched, including a blending process too, smoothing the borders of the unions.

The more heterogeneous are the images to join the more complex are these three steps. In the concrete case of the images acquired with a microscope, in general, there is quite homogeneity between them. The geometric distortion is not common, and if it appears it can be identified and corrected independently in each image. The possible illumination differences or vignetting can be also corrected independently. The search of the matching regions consists in finding simple overlappings between the images, as translation displacements. The stitching process is applied using rectilinear borders.

The stitching process for generating virtual slides has less complexity than the process for generating other kinds of mosaic images, like for examples panoramas. This characteristic allows to develop automatic stitching methods for virtual slides. Next a new automatic and efficient stitching method that exploits the features of the JPEG2000 standard is proposed.

Here in after we assume that the acquired microscope images are initially processed, during the unification step, and after that they are compressed with JPEG2000. It is necessary to configure the compressor so that the precincts have the same spatial influence in each resolution level, as it is proposed in [7]. That is, a determinated precinct size for the resolution level 0 is chosen, and this is divided by 2 successively for the followings levels. This allows to access to the codestream of the images with a finer granularity and to merge them without recodification. All the images would be compressed using the same number of resolution levels.

Due to the multiresolution representation of the compressed content of the JPEG2000 images, the second step of the stitching process can be made in two different hierarchical substeps, initial search and refinement, without having to decompress the entire contents. A graphic example of the search of the matching regions between two images can be observed in Fig. 3. For the initial search, it is necessary to decompress only the smallest resolution level. After finding the matching regions, they are decompressed, using the biggest resolution level, to refine the precision. In this way a considerable amount of memory and computational load is saved.

Once the matching areas are found precisely,

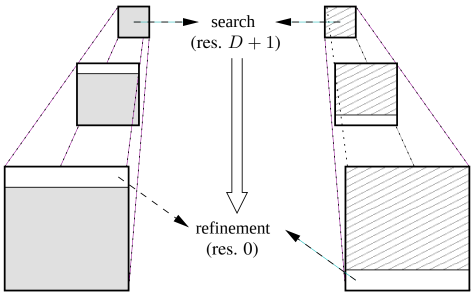

Figure 3: Example of the proposed two-steps search scheme.

the joining process is made in the DWT domain. This implies to make a multiresolution stitching, as it appears in the example of Fig. 4. From each subband from each resolution level the the regions to join are extracted. For example, if the region to extract of an image is defined by (x, y, w, h), horizontal and vertical position and width and height, respectively, it would be necessary to extract the regions $(x/2^{(r+1)}, y/2^{(r+1)}, w/2^{(r+1)}, h/2^{(r+1)})$ from the subbands LL_r, HL_r, HH_r y LH_r, for $r = 0 \ldots D-1$. Then the regions associated to the same subband, from each image, are joined. The final global result would be conceptually the same that the result of a DWT transform of the direct union of the images. Notice that the number of resolution level of the result is the same that the number of resolution levels chosen when compressing the images.

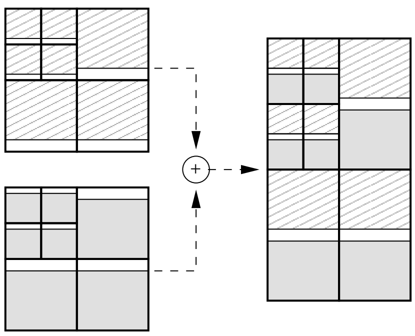

Figure 4: Example of the stitching process in the DWT domain.

There are two main advantages of stitching the images in this way: i) the frequential domain of the DWT allows a natural smoothness of the union borders, without losing information, and ii) thanks to the granularity given to the code-stream during the compression, the stitching does not require the recodification of the whole content of the images.

Image set	Num. of images	Image size	Time percentage
A	36	2618×1787	1.05%
B	25	3272×2469	0.38%

Table 1: Average time percentage for the proposed stitching method in relation to the simple stitching method.

The first advantage allows to avoid practically any additional later processing to smooth the union borders. These borders are observed in almost all the cases, losing quality the final composition result, very important in the context of virtual slides. These borders are practically erased stitching in the DWT domain

The second advantage allows to reduce at the maximum the requirements of computation load and memory. The stitching in the DWT domain does not require a complete recodification. Only those precincts that are intersected by the union border would be decompressed. That is, all the affected precincts from the images are decompressed in order to join them correctly, compressing the result. The rest of the precincts are copied without recodification, within the compressed domain.

RESULTS

The required time to make the automatic stitching between each pair of contiguous images, for two different sets, has been evaluated. Each image set is associated to a complete virtual slide. The images are compressed with JPEG2000 using 6 resolution levels, a code-block size of 64×64, with a precinct per code-block.

For the search of the matching regions the NCC (Normalized Cross Correlation) based on FFT has been used, also used in [8]. Two different stitching method have been compared: i) a simple method that consists in decompressing completely each image, search the matching regions, make a simple union and compress again, and ii) the method proposed in the previous Section.

The average time percentage for the proposed stitching method in relation to the simple method, for each image set, can be observed in Table 1. In Fig. 5 the detail of the union border for two images of the set A is also compared, for the two evaluated methods.

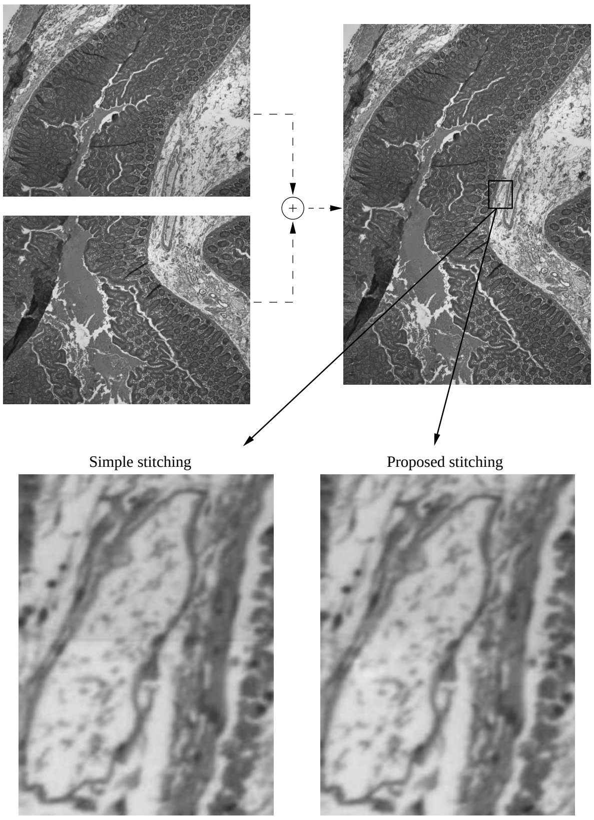

Figure 5: Comparison of the simple stitching and the proposed stitching.

CONCLUSIONS

In this paper the main features of the JPEG2000 standard have been analyzed in order to exploit them to build highly efficient telepathology systems based on virtual slides. A new automatic stitching method has been also proposed, based specially on the structure of this standard. This method reduces at the maximum the requirements of computation load and memory Moreover, using this stitching method, the union borders are automatically smoothed without losing information.

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