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Collaborative Compressed I-Cloud Medical Image Storage with Decompress Viewer

Israna Hossain Arka[a], Kalaivani Chellappan[a]*

[a]*Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor - Malaysia*

Abstract

Healthcare collaborative approach is anticipated to be an appropriate solution for disease management structure in the growing global population. Efficient disease management structure needs deep analytical skills in making effective decisions based on medical data. The nature of medical data being huge in size has been categorized as big data. Big data management in a collaborative environment needs multiple technological integrations. In this paper we have proposed an independent cloud based collaborative medical image storage and mobile viewer assisted with effective compression and decompression technique with unique security structure design. The proposed design has considered deep technology exploitation to offer medical image access via mobile devices by considering all the current constraints in terms of storage, image clarity and security. The proposed architecture allows both patient and medical practioners to have a cost effective approach in disease management and treatment process. It also introduces healthcare analysts and practitioners to the advancements in the computing field to effectively handle and make inferences from voluminous and heterogeneous healthcare data. Due to the broad nature of the topic, our primary emphasis will be on introducing healthcare data repositories, challenges, and concepts in data science. Not much focus will be on describing the details of any particular techniques and/or solutions in image compression, security and the medical field in particular other than convenient data access opportunity framework.

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Keywords: *medical imaging; cloud storage; compression; decompression; mobile devices; data security; collaborative.*

* Corresponding author. Tel.: +603-8921-6302.
E-mail address: kckalai@ukm.my; israna.hossain@siswa.ukm.edu.my

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1. Introduction

Medical imaging is the visual representations of the human body or parts of the body used in medical procedures taken using equipment utilizing electromagnetic radiation in order to reveal, diagnose or examine disease. Medical images are the main means of the present healthcare diagnostic procedures. These come from a board spectrum of imaging technologies such as plain X-ray (XR), ultrasound (US), computed tomography (CT), magnetic resonance imaging (MRI), digital mammography and nuclear medicine imaging including positron emission tomography (PET) and single photon emission computed tomography (SPECT).[1] There are recent developments of bio-imaging technologies such as functional magnetic resonance imaging (fMRI) and magneto encephalography (MEG) to identify the locations of human brain functions.[2] All these medical imaging generate a large amount of image data accompanied by important medical information. Some techniques result in a single image, such as X-ray of a broken bone, while other modalities, such as MRI scan, produce multiple images, which are referred as a series. If these series are taken over a certain period of time, these are referred as a study of a single patient. A single study can comprise as many as a thousand images, resulting in more than 15 GB of data.[3] Based on current trend, it is estimated that over one billion diagnostic imaging procedures will be performed in the United States during year 2014 generating about 100 Petabytes of data.[4]

These studies are often sent to a specialist for expert analysis and the results are returned to the patient's physician for further treatment. Thus there is a need for medical image sharing across all healthcare establishments including public hospitals, polyclinics and healthcare establishments in the private and charity sectors.[5] Users in medical imaging have multiple challenges for storing, indexing, maintaining viability and sharing their data. Addressing all these issues requires a constellation of tools, but not all of them need to be local to the site. In the past, film was the only medium used to share medical images with multiple health care services,[6] which was expensive and inefficient. Then appearance of compact disc (CD)[7] had advantages like low cost, portability and high storage, but CDs can be defective and unreadable over time and are often are not convenient to exchange. Then emerged technologies like peer-to-peer (P2P) systems[8] and cloud computing[9] that are capable storing and sharing medical records across autonomously managed heterogeneous healthcare information systems. Now the data storage challenges faced by users began to require professional information technology skills. With limited human resources and funds to maintain expensive large scale distributed infrastructures, the medical imaging users may be better served with an outsourcing strategy for some image data management aspects. Therefore, where and how to store these medical images in an efficient way becomes an important issue to be conquered.

With the recent developments of mobile, telecommunication and information technology, the concept of cloud computing is gaining serious interest from both industry and academia.[10] It saves the resources from buying and managing hardware; instead users rent virtual machines and storage space. Customers are charged using a pay-as-you-go model, based on various combinations of compute cycles, network bandwidth and/or storage consumed, and/or transactions executed.[11] In a storage cloud environment, users can store their data directly on a cloud provider like Amazon EC2 and S3, or they may use third party online storage services like Dropbox, Slideshare, SmugMug, etc. The latter provide value added services like backups, content sharing, collaboration, etc. to their users and may store user data into other cloud storage providers (e.g. Amazon S3).[11]

In this context, data intensive applications like medical image sharing platforms are increasingly becoming more prevalent in the emerging commercial domain of cloud-computing.[5] Ultimately online medical image transfer system allows physicians to build better and deeper referral networks, which in turn gives a rise in image volumes and requires an open platform for collaboration. Through the cloud, medical image sharing will help increase diagnostic and treatment accuracy; for example, ready drug allergies and current medications enable doctors to prescribe medication accurately and reduce unnecessary side effects. At the same time, cost reduction through best test selection which leads to more appropriate and organized treatment process. Besides, consolidating and storing medical image information in single centralized repository in the cloud instead of multiple Picture Archiving and Communication Systems (PACS) in different sites means health care providers can quickly access and share images across various departments and organizations. Collaborative centralization approach also ensures more reliable access security with single access key by authorized personal.

However, loading a large set of images will take time, an issue which needs to be addressed in a cloud system. Besides, since it involves a huge amount of images, a huge amount of storage space is required. On top of that, processing a lot of images in a scalable fashion leads to a high bandwidth utilization of the underlying networking infrastructure. Such a system needs to be able to serve multiple users concurrently, as well as transfer images between internal terminals quickly. Minimizing the storage space and bandwidth utilization as well as to sustain a high throughput under heavy access concurrency should be the point of interest, as these resources are paid according to the consumption.[10] Moreover, processing power of a medical imaging application should be more than a typical cloud storage to ensure that the system can run smoothly.[3] Obviously, the solution is to compress the medical images without any loss before being stored in the storage devices.[12]

Compression has already been proposed in cloud storage in two paradigms: compression managed explicitly at the application layer in Hadoop[13] while transparently at the level of storage layer in BlobSeer[10] data-intensive application framework. An algorithm is proposed that automatically adapts compression technique according to currently available network and processor resources to improve communication speed in wide area networks.[14] Adaptive compression technique is also applied for on-the-fly compression at the network stack directly to improve network transfer performance.[15] Another adaptive online compression is proposed where the compression algorithm is chosen by evaluating network bandwidth, server load, number of clients connected etc. and can be applied at a fixed set of n compression levels as a means to mitigate the effects of shared I/O to improve the efficiency of distributed applications which rely heavily on the network.[16] All the compression approaches mentioned above intend to conserve bandwidth and improve transfer speed, but are limited to end-to-end transfers rather than total aggregated throughput. Moreover, compression is applied in-transit only instead the data being stored remotely in a compressed fashion and therefore requests for the same data invoke new compression-decompression cycles every time.

Currently, storing the images safely, separation of ownership of images and resources used to store and manipulate the images on cloud are all big challenges in cloud computing.[17] After the medical data is stored in shared cloud datacenters, the control over how the data are stored and accessed is lost. Multiple classes of personnel may access the physical storage media and potentially read the data. Security issues involved in data storage and sharing through cloud are presented with a viable solution that eliminates these potential threats.[2, 18, 19] There are strong cryptographic methods that are capable to protect user files from unauthorized accesses, but they incur noticeable computational overhead and make it difficult for the infrastructure provider to optimize the storage space with effective compression and deduplication.[20] Moreover, it is also showed that compression works poorly on encryption data.[21] For images with minor differences, encryption keys generated from the images are different, which results in different cipher texts that cannot be compressed. Moreover, the encryption approach introduces additional overhead on the key storage and management.[22] To combat this problem, bit interleaved file system (BIFS) for cloud storage across multiple users' data is proposed following the principle of hiding images by re-ordering,[20] not substitution so that not only the computational overhead is reduced, but also structural regularity in images is preserved to facilitate compression.

Many organizations such as hospitals have adopted Cloud Web services in applying their network services to provide required network services and to avoid investing heavily computing infrastructure.[23] It is completely based on XML for all sent/received Web messages, which are bigger than the real payload of the requested services. This is creating high network traffic that could result in congestion and bottlenecks the performance of Web applications or stopping them completely. Targeting to improve the response time of web-services by compressing the exchanged XML messages, on-the-fly compression is applied.[24]

A physician generally has to work on a number of devices, including new tablets and mobile phones as well as traditional laptop and desktop PCs, by online access from different geographical locations. The 'thin' mobile devices are primarily characterized by limited internal storage and computational capacity, power consumption and complex synchronization steps to keep the product price down. Since internet access in available almost everywhere, a mobile device can overcome the limitations by offloading portions of application workload onto a cloud server to save execution time and conserve energy and by utilizing a larger storage capacity available over a network to meet their total storage needs.[25] The market for cloud-based mobile applications is estimated to grow from $400 million USD 10 year 2009 to $9.5 billion in year 2014, according to recent study by Juniper Research.[4] A framework is proposed to execute mobile applications in a cloud-based virtualized environment with sufficient security, privacy and guaranteed QoS.[26] This can be regarded as a standard framework for medical image sharing purpose also.

In this paper we propose collaborative storage approach between mobile devices and cloud storage for storing and sharing medical images. It exploits the image compression concept at storage service on cloud platform on 'one-write-many-read' basis resulting in better storage and bandwidth saving efficiency while delivering minimal impact on I/O throughput under heavy access concurrency controlled by mobile application and users.

2. Proposed System Architecture

Aimed to provide an efficient architecture for the storage and processing of medical images, we propose in this paper a cloud computing-based system. In designing the system for our needs, we have been guided by some assumptions. Firstly, all images from different sources are operated in the one-write–many-read schema (read-only). Original source sends images into clouds only once. Images that are already pushed into the cloud storage cannot be altered in the storage by client users. Secondly, the system has been design to accommodate simultaneous multi-centre storage. As shown in Fig. 1, the proposed architecture composed mainly of four blocks, the picture creation devices on the top left, the image viewer on the bottom left, the web database server and storage in the cloud.

The medical images generated by the image creation devices are first sent to the virtual medical image storage via the network with the TCP/IP protocol for compression. After that, the compressed images are then pushed to the image database for storage purpose, together with the decompression parameters as a metadata. The image database server is used to record the medical images of individuals. MySQL, which is a powerful and open-source application, has been proposed as the database platform. To bridge the viewer, i.e., the browser, and the database server, a web server is required. Apache, a widely used open-source web server is proposed to establish the proposed web portal.

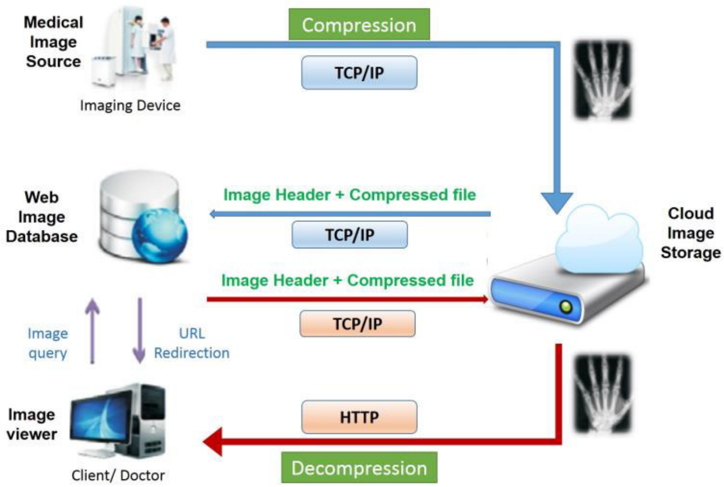

Fig. 1. Medical image sharing through cloud.

The client can now communicate with the web server through HTTP protocol, an application layer protocol which is based on TCP/IP protocol in the Internet hierarchy, accessing the images of individuals. When the clients, i.e., the viewer, are trying to access a patient's image, the database server will have the compressed image data retrieved and then sent to the viewer for decompression via the web server with HTTP protocol, and the client will see the image on the viewer on mobile devices.

Indeed, the decompression and processing of images are automatic and is therefore transparent to the clients. Compression is applied on the storage level to reduce computational complexity at hospital image source terminals and to ensure the uniformity of compression technique for all images from different sources. The viewer is packed with the decompression algorithm so that when the user wants to view the desired image, he can view the decompressed version of the image. This is done to reduce the number of bits to be transmitted over the network and to ensure a fast retrieval of the image. A detailed explanation on the compression and decompression will be given in next section.

3. Compression and Decompression of Images

3.1. Compression

Extensive work has been done in the field of compression and transcoding addressing various aspects at different levels of the system software stack.[11] Source compression could be the most effective since it can reduce network transmission cost by transmitting the compressed image directly to cloud storage. Every hospital terminal participating in cloud image storage needs a common compression strategy to make the aggregated performance effective. That is, some application programs should be installed on the source computer for the processing and compression of images in an efficient manner, which means the hardware devices, should be powerful enough. However, resource limitations like CPU, battery life and scratch space at the source devices can further limit the cost reduction of compression. Middle-ware based exchange of images in interactive or collaborative distributed applications has been discussed,[11] but in a situation when the intermediate service fails or operates out-of-order, then the implication of such services becomes more vulnerable.

We integrate compression in the storage service and handle it transparently. An appropriate algorithm to be selected for medical image processing that can remove the statistical redundancy efficiently, and thus achieve impressive compression ratio, as well as the actual bit rate can be achieved within the shortest time taken. Commercial remote access tools such as Citrix use lossy compression for remote viewing and hence are not suitable for medical imaging application.[27] Medical images with features that have their energy spread over numerous smaller coefficients are more sensitive in compression activity. These are regarded as random noise and discarded in the initial process. But in practical, fine, irregular textures also contain many small coefficients and tend to exhibit blurring effect at moderate level of compression. Examples include: white matter in a brain CT images, the trabecular pattern of bone XR images, speckles in ultrasound images etc.[28] That's why, sometimes preserving these structural textures become priority than to achieve high compression ratio. Moreover, lossy compression can also reduce the volume of cancer cell by removing some pixels and thus, provide wrong information about the growth of cancer in any part of the body.

In medical imaging approach, mostly only a small portion of the image might have higher diagnostic importance than others, but the implication of a wrong interpretation is high. Algorithms which deliver lossless compression within the regions of interest (ROI) and lossy compression elsewhere in the image, might be the key to providing efficient and accurate image coding to the medical community.[29, 30, 31] Such algorithms are termed as near-lossless compression schemes. Another approach is to maximize the overall compression ratio by dividing the image into multiple ROI and then compressing each region separately with its own compression ratio, instead of transforming the whole image.[32] It also helps to preserve textural characteristics. The authors presents and compares several new algorithms for ROI based near-lossless compression,[33] such as lossless coding with the S-transform, lossy wavelet zero-tree coding together with either pixel-domain or transform-domain coding of the regional residual. Moreover, Shape Adaptive wavelet transform and Scaling Based ROI, JPEG2000 Max-Shift ROI Coding, JPEG2000 Scaling-Based ROI Coding schemes are evaluated and compared,[34] in principle of reconstructed quality enhancement with high compression rate for medical image. For faster run time performance the compression algorithm can easily be changed to JPEG-LS,[35] standard of lossless and near-lossless coding, with some degradation on the actual bit rates.

3.2. Decompression

Read requests are simpler to handle. The user only needs to install software on computer or application on mobile devices or enter simple commands to use network services instead of storing images on computer. The decompress viewer looks up location information in its database and fetches image from the storage cloud provider. It decompresses the image in its original form and displays to the user. It also records and updates a few metadata associated with this image like last access time, access frequency, etc.

4. Security Issues

Reliability and security are the main concerns about cloud computing. Since the concept is still new, no safety standard has actually been developed; each company is following its own standards.[16] Our proposed method includes some important security services such as identity based authentication, encryption, decryption together with compression and decompression in cloud computing system. We exploit the mechanism of encryption at the main cloud storage server using secret key followed by compression of images while uploading to an intermediate server. Similarly, the compressed image will be decrypted at the main server and then the image will be decompressed and displayed on the viewer on-demand. Two layer of cloud storage is deployed solely for security purposes. The schematic diagram for securely sharing medical images through cloud is shown in Fig 2.

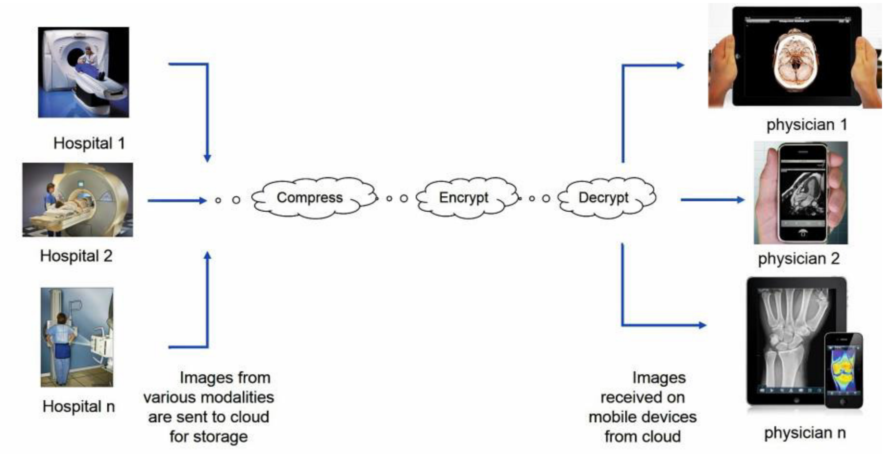

Fig. 2. Secure medical image sharing through cloud.

Compression is done before encryption because once the image file is encrypted, it will generate a stream of random data. Output of an encryption system should be indistinguishable, even by a determined attacker. The more we can ensure that the output of encryption contains no patterns, the harder it will be to decrypt. A compressor surely is not a malicious attacker, but it works by trying to find non-random patterns in the images that can be represented with less bits. However, a random stream, by definition, has no patterns. The compressor will not be able to find any pattern in encrypted text. That's why, encrypted images are incompressible. So we should compress image first, then encrypt the result, not the other way round. This way will not only achieve a good compression but also remove the patterns in the input image for the encryption algorithm and prevent frequency or similar attacks on encryption. Also, encrypting a shorter data stream is the bonus.[34]

Authentication processes are implied in both compression and encryption layers. Users receive secret key generated by main server through registered email address that is used for security services. The users receiving the image login to the main server with registered email id and password. After confirming the identities of each user, the main server will request for 'authorized person login' after successful authentication. User login into the cloud storage with his registered email id as user id and secret key as password and can view the images. Thus, two times authentication reinforces the security and ensures that only legitimate users can access the data.

One viewer device can be used by a single user at a time, which means that the case in which more than one user logs in to use a device is not possible. This is because GPU architecture is highly parallelized; it still does not support multiple concurrent user access, so image requests from storage would have to be served sequentially.[2] Performance analysis indicated that the authentication protocol is more efficient and lightweight than SAP,[17] especially the more lightweight user side. Being certificate-free, the authentication protocol aligned well with demands of cloud computing.

5. Optimization through Caching & Prefetching

In the compression system, we propose to incorporate in-memory cache for storing the recently accessed metadata and compressed image.[35] When there is a request for an image to be transmitted to user, at first it is checked if the in-memory cache has it. If the image is readily available, then the image is copied into the user-provided buffer. The read operation can be performed concurrently, i.e., threads can copy many images to the user buffer at the same time. If the image is not in the cache, then a cache miss is received, and consequently, new I/O requests are created for the missed image. Then the image has to be retrieved from the compressed image sets.

An in-memory cache can help reduce decompression overheads, if certain images are accessed repeatedly. We further improve performance by having the in-memory cache in conjunction with a prefetching mechanism with a high performance and low latency. It not only holds the recently accessed images, but also can make an intuitive fetching of the mages, that can be accessed at the very later instants, even before they are requested. The prefetching and caching mechanism in the compression system efficiently overlaps the data retrieval and decompression operations at application-level computation. Thus, it hides visible disk I/O cost and improves response time.

6. Future Research Directions

Medical images in the cloud are typically in a shared environment combined with images from other clients. Cloud based medical image exchange has unique attributes that raise many security and privacy challenges in areas such as data design, image security, user security, recovery, and privacy, as well as legal issues in areas such as regulatory compliance and auditing. The main research scopes are nevertheless to ensure integrity of the medical data if the server is not fully trustworthy, to test the efficiency of encryption solve the data confidentiality, the effect of encryption on dynamic data operations such as query, insertion, modification, and deletion, the process of image segregation and anonymization, while images being stored, transmitted and processed etc.

7. Conclusion

Cloud is an emerging approach for various medical imaging applications. A secure independent collaborative cloud-based medical imaging exchange can speed access to pertinent current and historical imaging studies. Hospitals deploying a medical image exchange can view and share images and reports with their referral partners in real time, without relying on physical media such as CDs. In this paper we proposed a cloud based medical image repository infrastructure that comprises of compression and decompression of images together with image caching and prefetching, which can be accessed through mobile imaging devices. With the proposed architecture, only an application is needed on the client host, which means the heavy burden on hardware upgrade can be alleviated making the system very feasible for practical usage, especially under limited resources. We examined the various security issues associated with this approach and discussed about an identity based authentication process for users. Finally we discussed the future directions for research.

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