COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE XXX (2013) XXX–XXX

journal homepage: www.intl.elsevierhealth.com/journals/cmpb

Effective management of medical information through ROI-lossless fragile image watermarking technique

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ARTICLE INFO

Article history:
Received 9 April 2012
Received in revised form
26 April 2013
Accepted 26 May 2013

Keywords:
Electronic health record
Personal health record
DICOM
Security
Privacy
Watermarking

ABSTRACT

In this article, we have proposed a blind, fragile and Region of Interest (ROI) lossless medical image watermarking (MIW) technique, providing an all-in-one solution tool to various medical data distribution and management issues like security, content authentication, safe archiving, controlled access retrieval, and captioning. The proposed scheme combines lossless data compression and encryption technique to embed electronic health record (EHR)/DICOM metadata, image hash, indexing keyword, doctor identification code and tamper localization information in the medical images. Extensive experiments (both subjective and objective) were carried out to evaluate performance of the proposed MIW technique. The findings offer suggestive evidence that the proposed MIW scheme is an effective all-in-one solution tool to various issues of medical information management domain. Moreover, given its relative simplicity, the proposed scheme can be applied to the medical images to serve in many medical applications concerned with privacy protection, safety, and management.

1. Introduction

Medical information is highly valuable and critical due to its importance in clinical diagnosis, treatment, research, education and other commercial/non-commercial applications, both for private and government organizations. During the last few years, due to the rapid and significant advancements of information and communication technologies medical data distribution and management systems have undergone a significant change, both in concepts as well as in applications. Hospital Information System (HIS) and Picture Archiving and Communication Systems (PACS) based on The Digital Imaging and Communications in Medicine (DICOM) standard (as advised by National Electrical Manufacturers Association (NEMA)), form the base of the modern integrated and sophisticated health-care delivery systems [1]. These systems provide easier access, effective manipulation and efficient distribution of medical information between hospitals. There are number of reasons for this medical information exchange, for example telemedicine applications (ranging from tele-consulting, tele-diagnosis and tele-surgery) to distant learning of medical personnel [2]. Electronic health record (EHR) technology has replaced the inefficient paper records paradigm and is available in various forms such as diagnostic reports, images and vital sign signals etc. It can also contain the health history information of a patient, such as demographic data, physical examination information, laboratory test results, treatment procedures, and prescriptions etc., which are highly confidential in nature [3].

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http://dx.doi.org/10.1016/j.cmpb.2013.05.027

On the other hand, these advances have introduced new risks for inappropriate use of medical information, given the ease with which digital form of data could be manipulated. Moreover, medical images have special characteristics and requirements. As well as, it is also concerned with legal and ethical issues regarding the allowable operations and disclosures that can be undertaken on them, since any degradation of the quality of the images could result in misdiagnosis [4,5]. Therefore, it is of paramount importance to prevent unauthorized access and manipulation of medical data, as well as to protect its confidentiality. These result in a need to design a system for effective storage, controlled restriction of manipulation and access of medical information, keeping the authenticity, integrity and confidentiality requirements of medical data intact for effective management [4–7].

Digital watermarking (DWM) which imperceptibly embeds information (watermark) within a host signal (cover) such as image, audio or video, is an emerging research technique for multimedia data management [8]. Original motivation of this technique was to protect copyright, but it has also been applied to a wide range of multimedia applications [9,10]. When it is applied to medical images, necessary steps are taken so that after watermark embedding, medical images can still conform to the DICOM format [11]. DWM techniques have the potentiality of becoming an all-in-one solution tool providing alternative and/or complementary solutions for a wide number of issues related to medical information management and distribution [4–7].

Many medical image watermarking schemes were proposed during the last few years [11–29]. In [13] Chao et al. have proposed a secure data-hiding technique based on the bipolar multiple-base conversion to allow a variety of EHR data to be hidden within the same mark image. This is different from the conventional encryption methods in which information or digital signatures are appended to the message separately. Two schemes of interleaving patient information (text and graphical signal) in medical images were proposed by Acharya et al. [14,16]. In [14], the authors have showed that reliability of transmission and storage of medical images interleaved with patient information by least significant bit (LSB) plane replacement scheme, over noisy channel can be enhanced using suitable error correction techniques. The other technique proposed by Acharya et al. in [16] is based on interleaving the texts and graphical signals in the last bits of discrete cosine transform (DCT) coefficients from the middle frequency range onwards. The blind MIW method described in [17] by Zain et al., is reversible and is used for authentication of DICOM images with good imperceptibility. This scheme is based on Region of Interest (ROI) and works in spatial domain. Woo et al. have proposed a multiple watermark method for privacy control and tamper detection in medical images with good imperceptibility [18]. In this scheme, an annotation watermark consisting encrypted patient information and a digital signature of the medical practitioner is embedded into the border pixels of images by discrete wavelet transform (DWT) based robust watermarking method. For integrity checking and tamper detection a tiled fragile binary watermark pattern is embedded in the LSB plane. In [21], Wu et al. have proposed two block based schemes for tamper detection and recovery using an adaptive robust watermarking technique with the modulo operation. Guo et al. have proposed a region based lossless MIW method for security enhancement and authentication using difference expansion of adjacent pixel values in [22]. This scheme does not introduce any embedding-induced distortion in ROI. In [23], Guo et al. have incorporated tamper localization capability to their previous method of [22] by partitioning an image into certain non-overlapping regions and appending the associated local authentication information directly into the watermark payload. A contextual based transform domain MIW technique is proposed in [25] by Nambakhsh et al. to embed electrocardiograph (ECG) and demographic text data as double watermark in PET images. Extensive review on different MIW schemes can be found in [6,7,29].

The present paper aims to reveal the potentials of digital watermarking in medical data management issues and proposes a novel method to enforce integrity, authenticity and confidentiality of the medical information, by embedding two different fragile watermarks in the two last LSB-planes of the medical image. Even though, there exist several medical image watermarking techniques, but most of them have several disadvantages: some of them are task and modality specific, whereas others suffer from the problem of low security, imperceptibility, payload capacity and without tamper localization capability. A comparative analysis of the advantages/disadvantages of the proposed technique over several state-of-the-art MIW schemes is given in Section 4 of this article. The proposed MIW method is modality and task independent, having high imperceptibility and payload capacity. Moreover, the proposed scheme is highly secure having several layers of security mechanisms. Watermarking by combining lossless data compression and encryption techniques, scattered embedding of the watermark bits in the embedding region, use of binary location map for the novel tamper localization method, all these aspects make the proposed scheme an effective novel MIW technique. Furthermore, the proposed scheme can be used as an all-in-one solution tool, which makes it a novel technique in the medical image management domain. The proposed method conforms to the strict specifications and requirements regarding medical data handling by preserving their visual/information quality and diagnostic value.

1.1. *Medical image watermarking: requirements*

Due to the special characteristics derived from strict ethics, legislative and diagnostic implications – integrity protection, confidentiality and prevention of unauthorized manipulation of medical information is very important. The risks are increased, when dealing with an open environment like the internet. This imposes three mandatory characteristics: confidentiality, reliability and availability [4].

- Confidentiality imposes that only the entitled users, in the normally scheduled conditions, have access to the information.
- Reliability has two different aspects:
  - Integrity: the information has not been modified by non-authorized persons, and

Please cite this article in press as: S. Das, M.K. Kundu, Effective management of medical information through ROI-lossless fragile image watermarking technique, Comput. Methods Programs Biomed. (2013), http://dx.doi.org/10.1016/j.cmpb.2013.05.027