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Contrast enhancement of ultrasound imaging of the knee joint cartilage for early detection of knee osteoarthritis

Md Belayet Hossain[a], Khin Wee Lai[a,*], Belinda Pingguan-Murphy[a], Yan Chai Hum[b], Maheza Irna Mohd Salim[c], Yih Miin Liew[a]

[a] Department of Biomedical Engineering, Faculty of Engineering, University Malaya, 50603 Kuala Lumpur, Malaysia
[b] Advanced Informatics Architecture Development, MIMOS, Technology Park, Bukit Jalil, Kuala Lumpur 57000, Malaysia
[c] Department of Clinical Sciences, Faculty of Biosciences and Medical Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia

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ABSTRACT

Knee osteoarthritis (OA) is one of the most common diseases among the elderly people. Typically, medical attention is not sought until the disease has progressed to a point at which it is not possible to treat effectively, often due to concerns over the cost of detection at an earlier stage. Ultrasound (US) imaging has a number of advantages as an imaging technique; apart from being a low cost diagnostic method, it is also non-invasive, utilizes non-ionizing radiation and portable. Due to progression of knee OA, the cartilage will experience a significant change in shape, and it becomes degenerated. After image processing using US medical imaging, it is possible to detect the cartilage shape change of the knee joint. Low contrast ratio and speckle noise are two main disadvantages of US imaging. The aim of this paper is to present a method for enhancing the contrast of the US image of knee joint cartilage in detecting early stages of knee OA. Conventional contrast enhancing methods are known to have some limitations. The objective of this paper is to propose a new contrast enhancing method which can overcome the limitations of the conventional contrast enhancing method. Most conventional contrasts enhancing methods emphasize only on one character. In the proposed method, the optimum value of contrast, brightness and detail preservation are considered. The proposed method is applied to find out the optimum separating point for segmenting the histogram of US image, for which optimum value of contrast, brightness and detail preservation will be preserved. In this method as well, three metrics, named as Preservation of Brightness Score function (PBS), Optimum Contrast Score function (OCS) and Preservation of Detail Score function (PDS), are defined.

1. Introduction

There are a number of medical imaging systems in modern health care, such as X-rays, computed tomography (CT), magnetic resonance imaging (MRI) and ultrasound (US). Among them, MRI is very expensive and not suitable for the implanted patients as well as for the patients who are suffering from claustrophobia. Meanwhile, CT emits high level of radiation, and has limitation for detecting fracture, and X-ray emits ionized radiation. Undeniably, all the mentioned medical imaging systems have some disadvantages.

Ultrasound (US) is the only system free from these limitations. It is applicable for any kind of patients. It is non-invasive, non-ionizing radiation, portable and less expensive. Real time imaging is also possible by using US medical imaging system. For operating X-rays, computed tomography (CT), magnetic resonance imaging (MRI), having experts on this particular field is mandatory. The operation of US medical imaging system, on the other hand, does not necessarily require any expert of that particular field. People without experience can learn in short time to take US imaging by using the US machine. It has high potential for use in imaging the resolution of US image for soft tissue [1,2] as high as MRI imaging. High frequency sound wave is also now used in US medical imaging. The frequency may range from 20 kHz to several GHz [3]. In case of rural area where transportation system is very poor, it is impossible to use X-ray, MRI, or CT for the diagnosis on the patients, but it is more convenient to use US medical imaging diagnosis as it is portable.

US imaging is useful in articular cartilage detection. It can directly display certain components of articular cartilage. Some

* Corresponding author. Tel.: +60 3 79677627; fax: +60 3 79674579.
E-mail addresses: lai.khinwee@um.edu.my, laikw2@gmail.com (K.W. Lai).

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advantages of US imaging system for detecting the shape of articular cartilage can be referred to [4]. In this study, we assess the intra- and inters observer reliability of US image in detecting cartilage abnormalities.

Attributable to its many benefits, the employment of US medical imaging is increasing at a rate of at least 8% per year. In 2005–2006, the total service by the ultrasound imaging was 4,716,394 where its number had increased to 6,251,413 by the financial year of 2009–2010. (Source: Date of processing Medicate data, Australia.) [5]. Ultrasound machines are also now available in different hospitals in Malaysia, for different types of imaging, such as uterus, ovaries, pelvic organ and the presence of a foetus in the abdomen. From the statistic of national medical device in 2009, it showed that ultrasound machine in private sector (62.7%) is more frequently used than in the public sector (37.3%) in Malaysia.

Presently, OA affects one-third of the adults worldwide, and the prevalence of this disease is higher among the elderly people [6]. Oliveria et al. [7] conducted a study to determine the prevalence of OA, based on the data from health maintenance organization in Massachusetts. The result of which revealed that OA of the knee joint is more common than the OA of other joints, as shown in Table 1. Table 1 also shows clearly that the OA disease is more common in women than men. The rate of the prevalence of knee OA in different countries is shown in Table 2. Indeed, OA is considered as a major concern to any health care bodies. The yearly financial cost of treating knee OA and other arthritis is much higher than other chronic diseases. For example, the treatment for arthritis in the United States is around 95 billion USD per year [8]. Note that, the amount excluded the cost of lost job of the knee OA patients. Through using demographic prediction, it was assumed that more than 20% of the population having age more than 60 years will be affected by knee osteoarthritis by 2040 [9].

Most patients diagnosed with early knee OA are reluctant to seek physician for treating knee OA resulting from unavailability and high cost of diagnostic tool in many clinics. For example, the MRI imaging costs about USD 280 in Malaysian public hospitals. Conventional x-rays are more economic, but not radiation free. US imaging can overcome these limitations as it is portable, radiation free, capable to generate a real time image, and also cost effective. Thus, for reducing the exponential increase of knee OA, it is very necessary to detect early knee OA.

Radiographies are very helpful in diagnosing OA because the affected joints will have significant appearance changes, such as: (a) Bones appearing closer to each other: As cartilage wears away, the joint space can narrow; (b) Cysts: As the body responds to cartilage destruction and attempts to stabilize the joint, cysts or fluid-filled cavities can form in the bone; (c) Increased bone density or uneven joints: When bones are no longer cushioned by cartilage, they might rub against one another, creating friction [10].

Ultrasound imaging is one of the most important imaging systems for knee joint and detecting shape of cartilage of knee joint. Though US imaging has a lot of advantages, it suffers from two drawbacks, namely speckle noise and low contrast. By enhancing the contrast of the US image, it is possible to detect the cartilage shape of the knee joints more deliberately. Histogram equalization (HE) is very popular method for enhancing the contrast of the image due to its simplicity and effectiveness [7,11]. It is widely used in case of sonar image processing [8] and medical image processing [9,12]. It is also used for speech recognition [13]. Based on the image cumulative density function, it functions by remapping the gray level of an image, which stretches the dynamic range of an image and enhances the contrast. However, the conventional HE system has some limitations. The aim of this paper is to present a new HE method which can overcome the limitations of the conventional HE methods.

2. Literature review

2.1. Non-technical

In case of osteoarthritis (OA) research ultrasound (US) becoming much popular day by day. US are used for imaging of erosion, effusion and osteophytes in osteoarthritis-affected knee joints. With patients having erosive OA, it is possible to detect more joint inflammation by using US, than by using clinical examination [14]. Wittoek et al. [15] has demonstrated that grey-scale ultrasound image are valid and reliable technique for soft tissue change in erosive joints. Radiology is the closest to the gold standard for epidemiological studies of knee OA [16]. The consistent feature of knee OA is inflammation and its contribution is observable with the progression of knee OA [17,18]. More sensitive modalities like ultrasound and MRI are required for the demonstration of inflammations. US can be used for visualizing structure of soft tissue such as cartilage [19,20], menisci [21] whose structure are related with the progression of knee OA.

Cartilage is a flexible and tough tissue found throughout the body. It has two main functions: acting as shock absorber and as mould. Unlike other tissues, cartilage does not have any blood supply. Cartilage can be classified into three classes: (i) elastic cartilage, (ii) fibro cartilage, and (iii) hyaline cartilage. The alternative name of hyline cartilage is articular cartilage. It is both springy and tough. It is found between the joints, ribs and around the windpipe (trachea). Articular cartilage damage is one of the most potentially serious and common type of cartilage damage between joints (usually knee joints). This damage results in pain, swelling and mobility loss. Articular cartilage can be damaged by three main impacts such as: (i) sudden accidental injury to the cartilage, (ii) a small section of cartilage and a piece of bone attached to it breaks away from a joint, which is known as osteochondritis dissecans, (iii) long term damage occurrence due to 'wear and tear', known as osteoarthritis (OA).

Cartilage loss is the main feature of the knee OA. By using MRI, it is possible to directly visualize the articular hyaline cartilage. Assessments of cartilage morphology from knee MRI are emerging as promising measures for monitoring OA disease progression [22]. Knee alignment is also associated with the progression of knee OA. By using joint space narrowing, it is also possible to determine the severity of knee OA. However, this possibility is limited by the unavailability of precise cartilage quantification when using medical imaging system. By using medical imaging system, it is possible to detect the small change of the cartilage of the knee joint, if image processing is accomplished. Several researchers reported that 4–8% of cartilage loss occur due to OA progression every year [22].

The US medical imaging system is known to possess a lot of advantages over other medical imaging systems. Despite having a lot of benefits, it suffers from two major drawbacks: having low contrast ratio and speckle noise. The aim of this study is to provide a method to enhance the contrast of the US image of knee cartilage for detecting the shape of cartilage, which will be very helpful for detecting early stage of knee OA. The conventional HE method is very popular due to its effectiveness and simplicity, but it has some limitations. The performance of conventional HE system is limited by three problems namely the brightness shift, detail loss and improper contrast enhancement. Brightness shift is the change of overall brightness of the image making it seems to be too much different from the original image; detail loss is the information loss after the HE operations; improper contrast enhancement is mainly caused by over enhancement that will create a wash-out effect that deteriorates the image instead of improving its visual appearance; improper contrast enhancement can also be referred to negligible intensity of contrast enhancement making the resultant image and