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Treatment planning for supracondylar fracture in humerus in children by image processing

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Abstract. Early treatment planning for supracondylar fracture of humerus (SFHs) in children by image processing research is mainly focus on developing a complete software solution for analysis and diagnosis of SFHs in children as well as provides a pre operational planning is the main objective of this study. However, as the manual process of measurement is usually complex, it is difficult to operate on clinic. This study proposes an effective technique for measuring a fracture angle in digital scan images taken on the personal computer. This approach is particularly promising in the context of find the angle of the fracture because of the high level of children needed in such accuracy in calculation of the fracture angle to fix it. Our goal is accurate detection of fracture angle. In this paper, we present a strategy based on advances in automatic interpretation of images applied to X-ray images scanned in situ. We propose a cognitive vision system that combines image processing, learning and knowledge based techniques with an advance algorithm to solve the problem. This system is illustrated with automatic detection and calculating Cubitus varus deformity at an early stage. We have compared our approach with manual calculation methods and our results showed that automatic processing is reliable. Special attention was paid to high fracture cases, which are crucial to take decisions whether to treat with an operation. The proposed method was validated with the results showing with the manual calculation and an operator can successfully make a measurement within a minute.

Keywords: Supracondylar fracture of humerus, SFHs, image processing, X-ray

1. Introduction

Fractures are common in the pediatric population. An estimated 15 million children visit the emergency department annually because of unintentional injury, and trauma to the musculoskeletal system accounts for half of these visits [1]. Supracondylar humerus fractures (SHFs) account for more than half of all fractures in the elbow region [2]. Anatomically, SHFs predispose the patient to vascular and neurologic injury. SHFs have been recognized as one of the more common fractures in children. According to Bullent SHFs are the most common elbow fractures in children, accounting to his findings it is around 60–80% of pediatric elbow fractures [3]. Cheng [4] reported it to be the second most common fracture in childhood (16.6%) and the most common before the age of seven. Unlike adults children usually sustain fractures in the upper limb. Of all the fractures in the upper limb the SHFs is most common injury but can result in serious complications if not treated appropriately. This is more common in children under the age of seven, affecting boys more frequently than girls [5]. The right hand to left side ratio is 2:3. The management of SHFs has evolved from a purely conservative approach to a more aggressive approach in recent years. The fracture is a metaphyseal injury that does not involve the physis or epiphysis. The injury is analogous to other periosteal sleeve injuries and therefore is capable of being successfully managed in a variety of ways as modeling in the sagital plane is almost always excellent.

The treatment of distal humerus fractures continues to present challenges despite advances in internal fixation. Successful outcomes are difficult to achieve be-

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cause of the complex anatomy of the elbow, associated osteopenia, and articular and metaphyseal comminution. Over the last two decades, however, enhanced operative techniques and implant designs have improved the reduction and stability of distal humerus fractures [6,7]. Considering the aging population and increasing life expectancy, and that most of these fractures require surgical treatment, the effects on health care costs and resources will be significant. Identifying and promoting strategies, such as osteoporosis treatment and fall prevention that may reduce the incidence of these injuries should not be overlooked. Unfortunately, the classification system does not account for factors such as the distal fragment height or coronal fractures, both of which significantly influence the difficulty of operative management, surgical technique, and patient outcome. Standard anteroposterior and lateral radiographs of the elbow are sufficient for most distal humerus fractures. There is accumulating evidence that the improved stability is not 100% correct due to mismatched calculation of angles.

This article focuses on the epidemiology, clinical SHFs is carried out to identify the fracture, find the displacement, plan the treatment and give solutions for later complications. To do the analysis of SHFs X-Rays will be taken in to image processing techniques. Treatment planning can begin once a diagnosis arrived at. It entails the formulation of the detail problem list, setting up of treatment objectives and finalizing the treatment execution plan after discussing with the patient or patient's guardians. Traditionally the location of landmarks for SHFs was performed manually using a tracing from X-ray film.

In this study the new approach has two important features. First, it applies powerful mathematical techniques to describe and analyze the fracture type, measure different angles and preoperational plan for complications of this fracture such as Cubitus varus deformity. Cubitus varus (varus means a deformity of a limb in which part of it is deviated towards the midline of the body) is a common deformity in which the extended forearm is deviated towards midline of the body. Cubitus varus is often referred to as 'gunstock deformity', due to the crooked nature of the healing [8, 9]. Furthermore it is able to handle and maintain variety of collection of patients and treatments related records. This study summarizes a highly accurate complete treatment plan for SHFs in children and to have a standard automated tool.

2. Methodology

2.1. Sample data for the application

Samples were taken for fracture analysis from the patients of Colombo National Hospital Orthopedic Unit, Sri Lanka. X-ray images of the Supracondylar fracture patients and previous manual analysis information are the main domain of the sample data for the application. To validate the accuracy, reliability and performance of the various algorithms of the system the X-ray images will be fed into the system, acquire the results of the algorithm and compare that information with the existing knowledge database. By increasing the number of samples use for validation of the system; can ensure highly precise functionalities of the system.

2.2. Image set

The set of 73 X-ray images of SHFs used in this study was obtained from by the Colombo National Hospital Orthopedic Unit, Sri Lanka. X-ray of the SHFs were acquired and saved digitally. HP 2355 digital scanner is used and color image uploaded to a laptop computer. In all cases, the image format used was JPEG, 24 bits and scanner of the X-ray was taken triplicate and obtained the best for image analysis.

2.3. Image format conversion

The most often-used color coordinate systems include the gray scale to binary and the hue, saturation, and intensity systems [10]. Examination and preliminary analysis of the different image formats indicated that the saturation component, which gives a monochromatic image, revealed the bone-fracture most clearly can be seen in the computer system. The Gray scale to binary was selected for training part of the system (Fig. 1).

2.4. System overview

As human biologists do, our system has to analyze X-ray images and to label interesting regions that correspond to objects of interest SHFs. To recognize a region as fracture, a human expert relies on manual calculation of the angles domain knowledge about fractures (e.g., Type 1, Type 2, and Type 3 fractures) as well as visual data that can be extracted from images (angle, shape and size). A software system must take into account both kinds of knowledge. To separate the

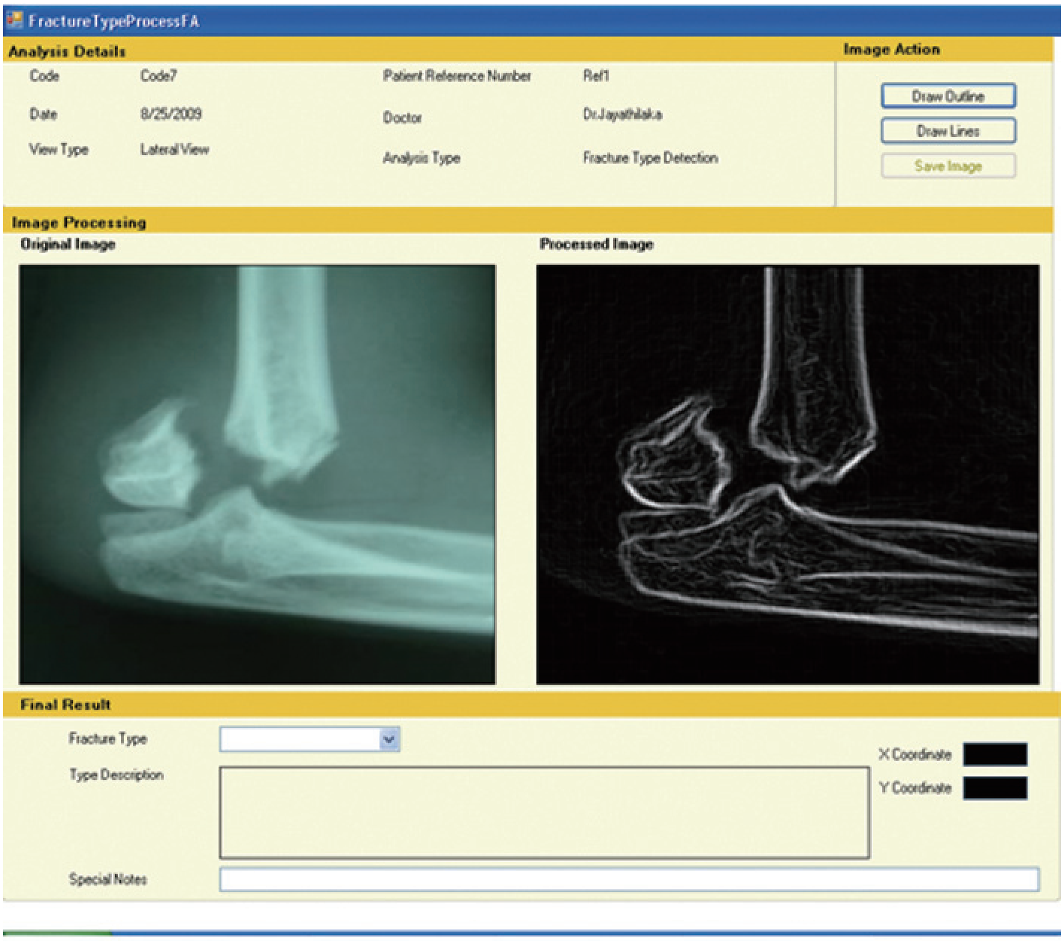

Fig. 1. X-ray image conversion to gray scale binary. (Colours are visible in the online version of the article; http://dx.doi.org/10.3233/IDT-2012-0137)

different types of knowledge and the different reasoning strategies, we propose architecture based on specialized modules, as shown in Fig. 2. It consists of three main knowledge-based systems, but overall system consists with a set of image processing algorithms and an initial learning module. The classification aims at selecting interesting regions in images. To this end, it triggers image-processing requests and interprets the numerical results into higher level concepts, i.e., (parts of) objects of interest. It retains only the regions corresponding to target fractures and returns their number to the user.

Our system goes through four different phases when solving a problem of fracture analysis. Namely, these components are image analyzing component, fracture analysis component, complication detection component and data manager. The image analyzing component will read digitized X-ray images into the system and fracture analysis component will analyze them to identify the outlines and fracture analysis area to precede the fracture diagnosis. Based on the identified fracture analysis details doctors can do the treatments. Treatment plan details can be feed to the system through the data manager component. Complication detection component will find the operative angle of Cubitus varus deformity. The data manager will further support to maintain analysis information, prediction information and patients' diagnosis information. In addition to managing information in persistence media, the data manager is responsible for various report generation functionalities.

2.5. The image analysis component

The image-processing task itself is achieved by a program supervision [11] knowledge-based system. Pro-

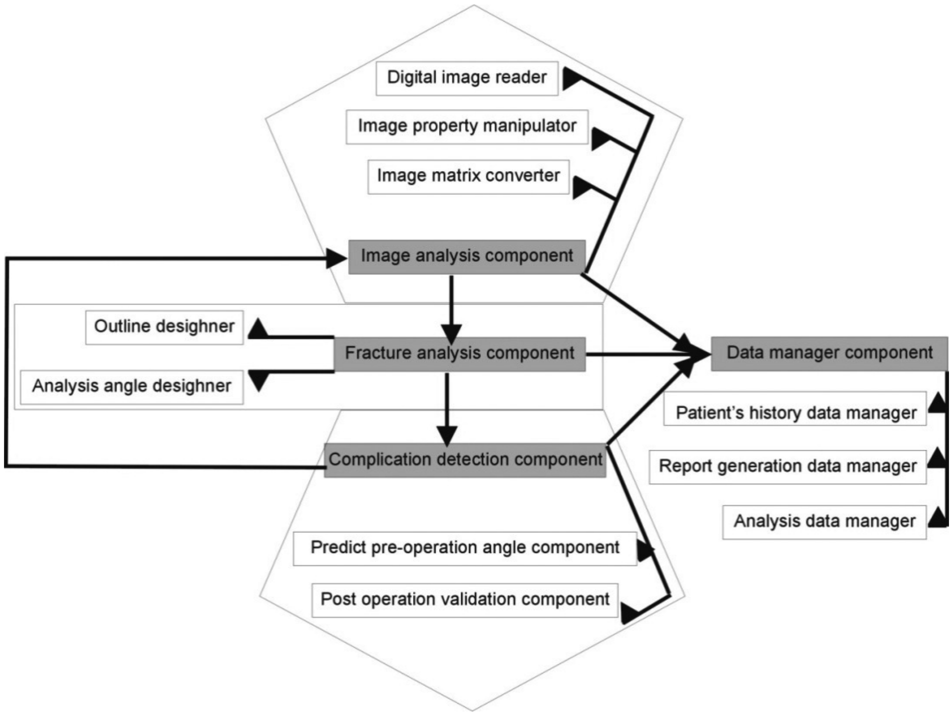

Fig. 2. Architecture of the system overview.

gram supervision techniques make it possible to automate the use of complex programs, i.e., to plan and control processing activities. In this system, the image analysis component will contain three components which are namely the digitized image reader, image property manipulator, and image-matrix converter. The digitized image reader will read the negative scanned X-ray image into the system. Necessary image manipulations such as image scaling, image format changing, image cropping . . . etc. are provided by the image property manipulator. The image-matrix converter will convert the digitized image into matrix format for highly accurate image processing functionalities. The supervision system controls the use of the image processing sub-tasks, as stated. It is based on knowledge about the programs, their input/output data, their applicability conditions, their possible combinations, and the necessary information to run them in a smooth platform.

2.6. *Fracture analysis component*

Similarly, once the objects extracted follows with image analysis, then comes fracture extraction, computes the attributes corresponding to each region, according to the domain feature concepts (e.g., shape and size descriptors) and to the operator graph. Fracture analysis component consist of outline designer, analysis angle designer. Using the outline designer will generate the elbow outline based on identified landmarks and color variation algorithms. The Analysis angle designer will support to mark the analysis angle points, automatically draw the angles and calculate the necessary angles and distances for fracture analysis. Based on the angular and distance measurements doctor can identify the type of the fracture and the displacement to do the surgery. The process runs up to the last program in the decomposition (in the example, outline designing and analysis angles). Finally, the supervision of the system returns a set of candidate areas to the classification fracture analysis. Each area has an attached set of computed numerical descriptor values.

2.7. *Complication detection component and data manager*

Based on the first two stages of the information provided by the user, different modules will be called in order to make a multi-expert diagnosis. The complication detection component will contain two software components which are namely predicting pre-operation angle component, Post operation validation component. The system predicts pre-operation angle component will provide a functionality to visualize the angle before the actual surgery happens. Post operation validation component will validate the angle after the treatment. Overall system then tries to determine the kind of complication detection, to suggest a precise treatment which will be sorted by urgency level and available methods in the particular fracture. The data manager will contain three software components which are namely analysis data manager, patient's history data manager and report generation component. The analysis data manager is responsible for maintaining all fracture analysis related data such as digitized X-ray image information, image processing intermediate information, fracture analysis decision information, diagnosis decision information, treatment planning information, and complication prediction information. Patient's history data manager will be responsible for maintaining the diagnosis and treatment history information. Finally report generation component will do the various report generation processes.

3. Results

3.1. Automatic identification of the elbow outline

The system has been tested on a database composed of representative samples of 73 images of the SHFs radiograph is scanned in to the computer. The study target after image acquires, and developed tool automatically loads the image and draws the outline of the elbow based on the selected algorithms. Primarily color variation of the digitized image is used to identify and highlight the outline of the patient's bone fracture (Fig. 3). Few images processing and image outlining methods were analyzed to select the best method for cephalometric analysis and identified that edge detection based on color variation of an image can be used for this purpose. To be suitable the outline for the fracture analysis it should clearly outline the soft tissues of the digitized image and bones or the skull. But in practically raw digitized images might have some garbage shadows that might lead to incorrect treatment planning. For the better results it should reduce the additional lines drawn on the image. For this purpose we can sharpen the image.

The system provides facility to generate the outline with the minimum effort and he doesn't need to go manual outline drawing that leads to reproducibility errors and measurement deviations errors. By providing facility to orthopedic expert to adjust the outline detection, the system provides very useful feature where they can come with high accurate bone outline with the minimum effort. Accuracy of this method is really high since no human errors and 100% accurate outline detection based on the color variation of the originally digitized image, manual method maximum accuracy gain was 85% only.

Edge detection of an image totally depends on the image quality, image type, image format. So the one particular edge detection algorithm might not applicable with different image qualities, different image types and different image formats. Through the process of development, it is identified and analyzed a suitable image processing algorithms for edge detection of the X-ray image to identify the outline of the X-ray image without human interaction. The Fig. 3 explains the analyzed methods are Sobel edge detector, and Canny edge detector, Difference edge detector. Following figures illustrate the output of the different methods. The developed system is based on the best edge detection algorithm which is called Sobel edge detector because it gives the best output to carry out the analysis.

3.2. Identification of the landmarks to determine the type of fracture and angle calculation

User can locate the landmark on the image. Landmark identification process also automated and developed tool can perform analysis based on identified landmarks. This overcomes the errors usually encountered in the manual identification of land marks. This usually overcomes the various errors incorporated while using manual methods. The procedure of computerized automatic identification has the potential to increase accuracy and improve doctor's ability to correctly diagnose the fracture analysis problems. Based on the fracture analysis carried out, the system will prompt the users to identify the required landmarks. Only the doctor needs to identify the type of the fracture required landmark on the outlined image.

In our system two lines must be drawn to evaluate alignment. The radio-capitellar line is drawn from the middle of the radial body through the capitellum and should always transect the capitellum in half. The anterior humeral line is drawn from the anterior cortex of the humerus through the capitellum and this line should cross the capitellum at the anterior 1/3rd. This patient with a Type I fracture has the anterior humeral line transect the tip of the capitellum which is indicative of a fracture (Fig. 4A).

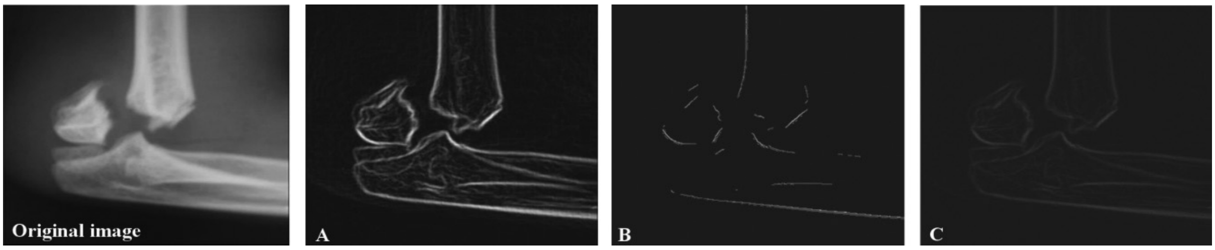

Fig. 3. Image processing by different output styles, From Left to right: Input image, A), Output of "Sobel" method; B) Output of "Canny" method; C) Output of "Difference Edge" method. (Colours are visible in the online version of the article; http://dx.doi.org/10.3233/IDT-2012-0137)

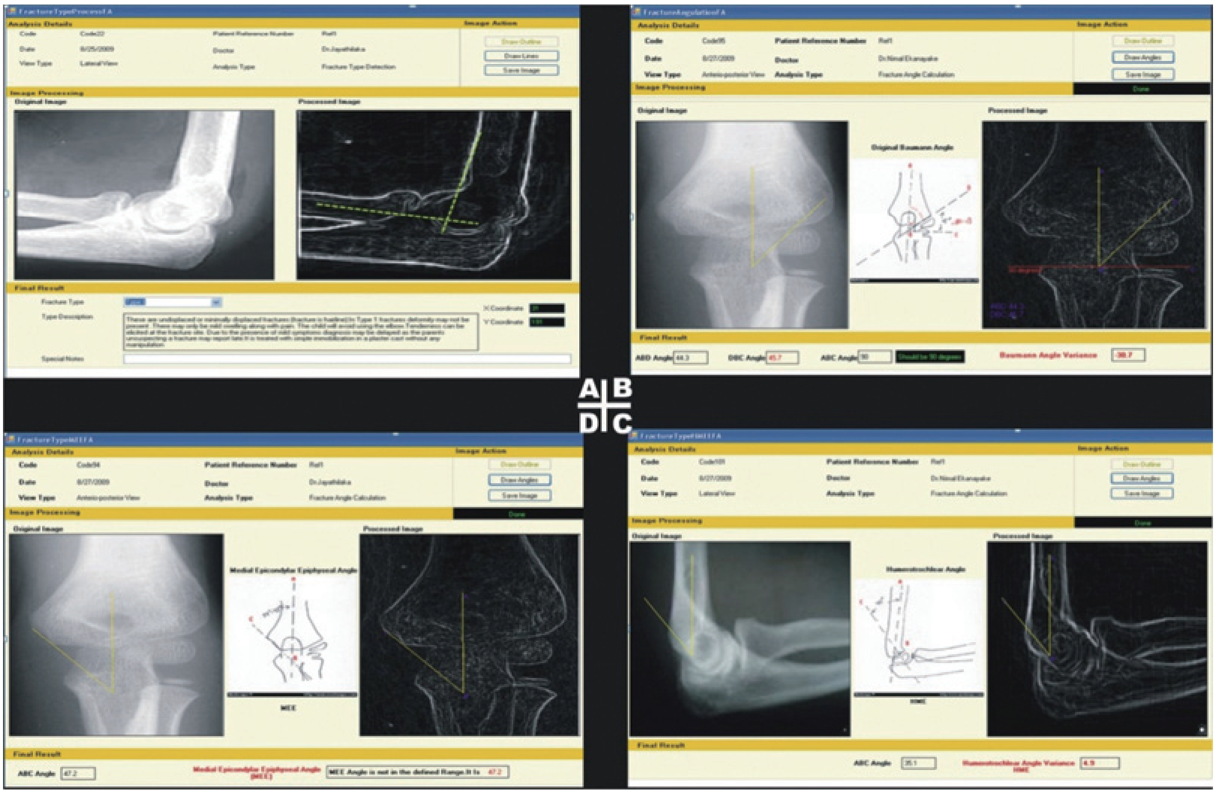

Fig. 4. Precise positioning and angle calculation of SHFs- A) Detecting the type of Fracture; B) Measuring the Baumann Angle; C) Measuring the HME Angle; D) Measuring the MEE Angle. (Colours are visible in the online version of the article; http://dx.doi.org/10.3233/IDT-2012-0137)

Accuracy of the fracture angle calculation is really crucial to come with the accurate treatment planning. Since the analysis deal with very small angles and due to small angle changes treatment change widely accuracy of the calculated angles much more emphasis. Once the user come up with properly outlined image as discussed above for the angle calculation he/she only needs to identify the points or landmarks on the outlined image. Once the landmarks identification done the system will automatically draw the required angles and calculate the required angles. Based on the calculated angels, the system is capable of deicide the adequacy of a subsequent reduction of the patient. The system is capable of measuring of angles clock wise or anti clock wise for entire 360 degrees. It considers clockwise angles as positive and otherwise negative angles. Direction of the measurement is also considered to the angle measurements (Fig. 4. B,C,D).

3.3. *Preplanning for Cubitus varus deformity and diagnostic and treatment of SHFs*

The best method of measuring, the fracture of SHFs is Cubitus varus by the distal end of the humerus.

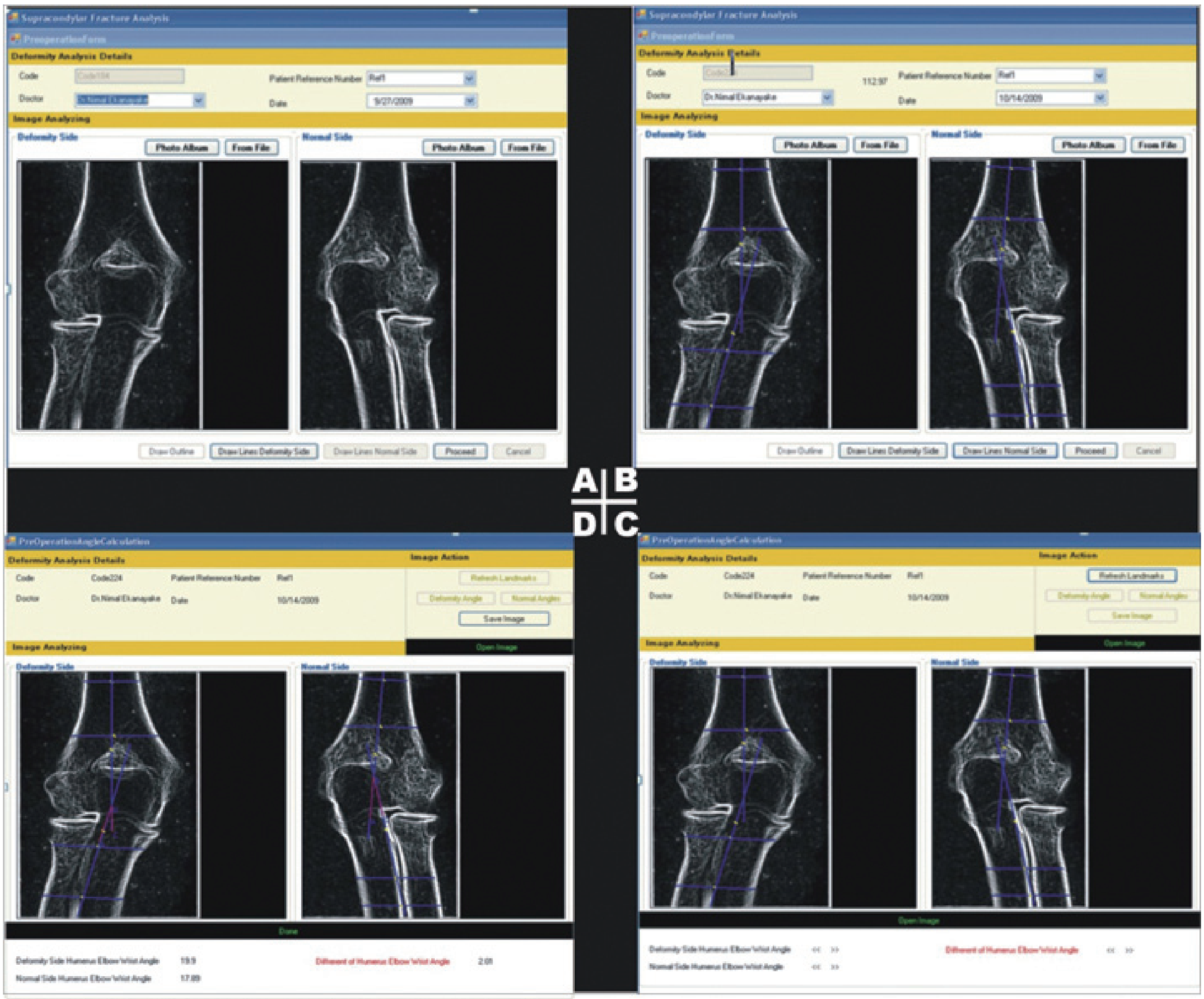

Fig. 5. Preplanning for Cubitus varus deformity A) Draw outline of pre operation planning for Cubitus varus; B) Draw lines of pre operation planning for Cubitus varus; C) Refresh landmarks of pre operation planning for Cubitus varus; D) Angle calculation of pre operation planning for Cubitus varus. (Colours are visible in the online version of the article; http://dx.doi.org/10.3233/IDT-2012-0137)

The humerus-elbow wrist (HEW) angle is measured by drawing a line along the longitudinal axis of the humerus. The line intersects a line drawn from the middle of the distal end of the humerus to the ulnar aspect of the distal end of the radius. Preoperative assessment determines the amount of correction necessary (Fig. 5 A,B,C,D).

One uses anterosposterior radiographs of both arms. The HEW angle is determined for both, and a tracing of both arms is made .The tracing of the injured arm is reversed and overlaps the tracing of the uninjured arm so that the ulna and radius of both arms overlaps. The difference in the HEW angle is then determined and the difference equals the amount of correction.

Use problem oriented approach as process of fracture diagnosis and treatment planning process. This is requires the collection of an adequate database of information about the patient and clearly stated problems. It is important to recognize that both the patient's participation and the doctor's observation needed in formulating the problem list. Once the patient's problem identified and prioritized following issues might be faced in determining optimal treatment plan.

We have also compared our results to a manual method of identification and angle calculation as shown in Table 1. This table raises several remarks. First, in the automatic mode, our prototype currently detects less error rate comparative to manual method. New developments will allow us to identify less than 1% error rate. Second, manual mode operations are achieved

Table 1
Method comparison for identification and angle calculation in a SHFs

	Manual identification and angle calculation	Automatic identification and angle calculation
Number of samples	85	73
Total cumulated time needed for all operations	4 hours	1 hour maximum
Accuracy	80–85%	97–100%
Error rate	5–15%	Less than 3%
Delivery of results	2 hours	10 minutes
Advantages	Discrimination capacity	Quick delivery of result
Disadvantages	Need of a specialized operator	Anyone can be the operator

in a research laboratory with X-ray with magnifying tools and protractor and it is time constraints; however, under automated system we have overcome the barrier. Third, the manual mode is limited by human capacities such as need of specialized doctors to calculate it, which automated progressively decreases while the time passes due to tiredness and repetitively.

4. Discussion

In order to validate the feasibility of the proposed SHFs in the previous section, 73 Supracondylar fracture images, taken by Colombo National Hospital Orthopedic Unit, Sri Lanka during 2009–2010, were tested. These X-ray images were taken according to the proposed methods. One single operator was assigned to process the X-ray image by running the program. The specifications for running this program on a PC were: Pentium 4–2.0 GHz CPU, 512 MB RAM, Windows XP, Microsoft Excel, Matlab, .NET, and Microsoft SQL installed.

The results for each X-ray image scanned during a 10min session were recorded. We have also compared our results to a manual method of identification and angle of the fracture (Data not shown). Comparison raises several remarks. First, in the automatic mode, our prototype currently detects all most all 3 types of fractures and it allow us to identify more classes, in almost the same amount of time. Second, manual mode operations are achieved in a research laboratory with optical magnifying tools and no time constraints; however, under production concern automatic mode gives precise value and premade operation instructions to the doctor to make the operation success.

Compared to the system proposed by Bauch and Rath [12], our system appears simpler and more precise. Indeed, their system uses a heavy experimental protocol combining a mobile suction mechanism to collect optical recognition system to analyze image exist some works concerned with genericity, at least to some extent, or with cognitive properties. For instance, we can cite [13] who have also as objective early disease detection, and who propose a versatile algorithm to identify and count fungal spores. They have also proposed a generic method [14] to represent and compare irregular natural shapes on images (leaf shapes). Perner et al. [15] introduce case-based reasoning to accommodate variations in the appearance of natural objects; the contents of their cases play a similar role as our visual descriptions. Manh et al. [16] propose to introduce a priori knowledge about the shape of objects to detect (in their case weed leaves) to guide the segmentation. In El-Helly et al. [17], the authors describe a biological expert system enhanced with vision techniques, while in our system it is rather the fracture analysis system, which is enhanced by knowledge based facilities. Closer to our approach, an experimentation framework, which is proposed in Ching et al. [18] in A simple and effective digital imaging approach for tuna fish length measurement compatible with fishing operations. Our framework for SHFs based tracking is flexible and modular to compare and combine algorithms; in our case this is the role of the program supervision system.

5. Conclusion

A PC-based software program to treatment of SHFs digital imaging technique was developed in this study. The software program is equipped with functions of automatically find the SHFs. The program, with a user-friendly interface, has a manual mode and an automatic mode for find fracture angle estimation. The effects of distortion correction and operation positions were tested and analyzed. It is worth noting that our proposed method does not require the information about manual calculation. With slight modification, the developed approach could be adapted to various applications concerning multiple fracture analysis and measurement of plants or children. The Implemented system is using image processing algorithms to understand the X-ray image and identify the information about the input .NET language will be used to implement the system since most widely used languages in the world and accuracy, security, modularization and performance is comparatively high. Matlab application is used to implement image processing algorithms. Microsoft SQL Server 2005 will be the backend for the proposed application.

The project life cycle of the SHFs system focuses on developing four major components. These components are Image Analyzing Component, Fracture Analysis Component, Complication Detection Component and Data Manager. The Image Analyzing Component will read digitized X-ray images into the system and Fracture Analysis component will analyze them to identify the outlines and fracture analysis area to precede the fracture diagnosis. Based on the identified fracture analysis details doctors can do the treatments. Treatment Plan details can be feed to the system through the Data Manager Component. Complication Detection Component will find the operative angle of Cubitus varus deformity. The Data Manager will support to maintain analysis information, prediction information and patients' diagnosis information. In addition to managing information in persistence media, the Data Manager is responsible for various report generation functionalities.

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