Development of Intelligent Setting System for Fracture Based on X-Ray Image

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Abstract. In order to achieve micro-wound, intelligence and high efficiency for fracture setting, intelligent setting system for fracture is proposed in accordance with biomechanics and fracture therapy theory. In the comprehensive medical system based on C-shape-arm X-machine, image processing and analysis is the core, programmable logical controller and stepping motor are important driving parts controlling mechanical parts. Six degree of freedom dynamics sensor ensures to control accurately force and moment. On the foundation of analyzing X-ray image peculiarities, method of processing and analysis is put forward, combining time domain with frequency domain. After mining domain knowledge in depth, setting actions is quantized into three non-continuous steps and is parameterized into two angles and one distance aiming at femoral-neck fracture. Objective features are extracted by virtue of three power polymerization curved surface fitting. Master-slave reference frame is advanced to solve a question that basic standard for parameters calculation is difficult to be determined. At the same time, four-group-sixteen-frame algorithm is put forward to solve a problem that the load value is unable to be calculated and applied precisely in the process of treatment of delayed union and non-union of fracture. Clinic experience proved that the system can help orthopedist to correctly and reliably complete fracture setting. And the system has many advantages such as micro-wound, low medical cost and low infection ratio, in comparison with traditional operation setting and manipulator setting.

1. Introduction

Different methods for fracture setting should be used in accordance with different fracture category, different damage degree and different merging injury. Traditional attaching manipulator for fracture setting includes fracture setting table, big tractor, small tractor, multi-joint pressure apparatus and so forth. Though fracture setting table remains wounded part of a patient’s body in suitable situation for capturing image, it restricts orthopedists to flexibly implement setting operations. While big or small tractors being used, the orthopedists can move the patient’s body by means of them, but the tractors must be fixed on the wounded bone of the patient and many holes must be drilled through the bone. Moreover, traction on single side easily produce eccentric force causing bone malformation after
fracture coalescence[1]. These attaching instruments not only can bring about serious wound, but also are poor in flexibility and degree of accuracy for fracture setting. Intelligent setting system for fracture can overcome shortcomings of the traditional instruments, serious wound and high infection rate. The system achieves micro-wound and intelligence for fracture setting. And it can apply force or force moment in precise term according to clinical demands, greatly reduce fault rate.

2. Operating principle of system
In the setting system, setting for fracture is completed by mechanical part working in coordination with driving control part under the control of software system, the principle is shown figure 1. The mechanical part is composed of mechanical driving apparatus and fixation apparatus fixing distant end of fracture part, the mechanical driving apparatus includes machine arm linked in a C-shaped rack, universal driving shaft, gear, lead screw, and sliding way. The mechanical part, controlled by the driving control part can accomplish twelve setting actions, left or right shift, left or right swing, up or down swing, push or pull of a main shaft, left or right twist of the main shaft. Six freedoms force sensor is able to real time feed back required parameters, ensure apply safe force or force moment. Programmed Logic Controller (PLC) is the core in the driving control part. PLC will send a pulse to step-by-step electric machines, the logic value of output determines on rotation directions, rotation subsequence and linkage order of the machines. At the same time, PLC accepts commands and parameters from the sensor, achieves precisely controlling and locating to setting for fracture.

3. Characteristic analysis and enhancement processing of X-ray image
X-ray image is a plane image of overlying information of different depth of tissue in human body. Owing to the mutual overlying of projection in many layers, projections of some tissue will be not clear for countervailing projections[2]. So, the tissue is very difficult to be clearly displayed. A frame of original X-ray image captured by X-ray machine is shown in figure 2. Through Observing histogram of the image (see figure 3), two conclusions will be drawn that intensity in the image is very
distributed on a convergent area and intensity difference between neighboring two pixels is very small. It indicates that the original image has low contrast and low sharpness.

![Figure 2. Original X-ray image.](image1)

![Figure 3. Histogram of the original image.](image2)

Histogram equalization can enhance image contrast, being similar with image intensity distribution function. Fourier transform is the most typical transform method in conversion of time domain and frequency domain[3]. In frequency domain, energy of the image is centered on the low frequency of component, the high frequency of component being corresponding on edge feature only possesses a few of energy (see figure 4). Experiments demonstrate that histogram equalization is suitable for enhancing contrast of X-ray image and that homomorphic filter based on Fourier transform is suitable for enhancing sharpness of the image. The image being processed is shown in figure 5.

![Figure 4. Fourier frequency spectrum of the original image.](image3)

![Figure 5. X-ray image after being enhanced.](image4)

Processing and analysis after the image being enhanced include mostly image segmentation, extracting and thinning edge, extracting feature points and lines, calculating feature parameters.

### 4. Quantization and parameterization of setting features

Clinically, unarmed setting actions for fracture are derived from clinic experience for long time and intuition, deciding setting effect. In the system, the actions must be epitomized, quantized and parameterized, in order to successfully use the mechanical part and driving control part to simulate the unarmed setting actions. In view of femoral-neck fracture being high incidence of a disease in senior citizen, a strategy on epitomized, quantized and parameterized is first advanced. Namely, the unarmed setting actions to femora-neck fracture is epitomize into three operations, push or pull, left or right shift, rotate inward. The three operations are quantized into nine points and six lines. The points and lines are parameterized into two angles and one distance. The strategy is shown in figure 6.
Function $f_3(x,y)$ representing X-ray image after being enhanced can be cubic polynomial fitted by means of least square method, if $k_i (i=1,2,3,\ldots,10)$ is decided by gray value of pixel in the X-ray image, $\theta$ is used to express the gradient direction angle, then

$$\frac{\partial^2 f_3(x,y)}{\partial \theta^2} = (6k_7 \sin^2 \theta + 4k_8 \sin \theta \cos \theta + 2k_9 \cos^2 \theta)x + (6k_{10} \cos^2 \theta + 4k_9 \sin \theta \cos \theta + 2k_8 \sin^2 \theta)y + 2(k_4 \sin^2 \theta + k_5 \sin \theta \cos \theta + k_6 \cos^2 \theta)$$

To any arbitrary boundary point, $\alpha$ equals a minimal distance between two neighboring pixels. $t$ is a given threshold. When

$$\left.\frac{\partial \theta}{\partial \lambda}\right|_{(0,0)} \geq t$$

The point is ascertained as a corner. According to the algorithm, desired features can be extracted, including characteristic lines $l_1$, $l_2$, $l_3$, $l_4$, $l_5$ and $l_6$, the characteristic angle $\alpha$ and $\beta$, characteristic distance $d$.

With rotation or motion of X-machine and posture of a patient, location of fracture part will change. So, a master-slave reference frame method (see figure 6) is first advanced, supplying standard for calculating parameters. Bottom boundary and left boundary in image displaying area is separately assigned as $X$ axis and $Y$ axis of master reference frame, $(O(X_0,Y_0))$ is the origin. Medial shaft of femoral diaphysis ($l_1$) is assigned as vertical axis in slave reference frame, an intersection point between the vertical axis and the bottom boundary is the origin $(O'(X_0',Y_0'))$, horizontal axis $X'$ can be easily assigned. Let $(x_w,y_w)$ represent any point in the master frame, corresponding point being defined as $(x_v,y_v)$ in the slave frame, $\gamma$ represents the intersection angle between the $X$ axis and the $X'$ axis. Then

$$x_v = \left(\frac{y_w^2 + (x_w - X_{0'})^2}{1 + \frac{(y_w + (x_w - X_{0'})\gamma)^2}{x_w - X_{0'} - y_w\gamma^2}}\right)^{\frac{1}{2}}, \quad y_v = \left(\frac{y_w^2 + (x_w - X_{0'})\gamma y_w}{x_w - X_{0'} - y_w\gamma^2}\right)\frac{1}{2}$$

Then, the value of $\alpha$ can be calculated by (4), the value $\beta$ can be easily calculated by (5), the value of $d$ can be calculated by the equation ($d=|Y_v|+Y_{vd}$).
\[
\alpha = \left( \arctg \frac{y_{v1} - y_{v2}}{x_{v1} - x_{v2}} \right) \times \frac{180}{\pi} \pm \left( \arctg \frac{y_{v1} - y_{v5}}{x_{v1} - x_{v5}} \right) \times \frac{180}{\pi} \tag{4}
\]

\[
\beta = 90 \pm \left( \arctg \frac{y_{v1} - y_{v2}}{x_{v1} - x_{v2}} \right) \times \frac{180}{\pi} \pm \left( \arctg \frac{x_{v3} - x_{v4}}{y_{v3} - y_{v4}} \right) \times \frac{180}{\pi} \tag{5}
\]

Specially, real distance implemented has relations with a distance between a patient body and collecting screen of X-ray.

5. Sixteen frames algorithm for press calculation

For some patients, nonunion or delayed union of facture can be caused, because blood supply or entire fixation is not full. The press value promoting them to recover is very difficult to be decided and controlled. Too great press can cause malfunction or dysfunction. Four-team-sixteen-frame algorithm is able to accurately calculate the press by way of appropriate segmentation to irregular section of fracture part. The press value can be calculated by (6).

\[
P = \frac{\sigma}{k} \cdot \frac{1}{16} \left( \sin \alpha_1 \cos \alpha_2 \cos \alpha_2 + \sin \alpha_1 \cos \beta_1 \sin \beta_2 \cos \beta_2 \right) + \left( \sin \beta_1 \cos \alpha_1 \sin \beta_2 \cos \beta_2 \right) + \left( \sin \beta_1 \cos \beta_2 \sin \alpha_1 \cos \beta_2 \right) + \left( \sin \alpha_1 \cos \beta_2 \sin \alpha_1 \cos \beta_2 \right) \tag{6}
\]

In (6), \( \sigma \) is an optimum press value, being a constant. \( k \) is a multiple, being a proportional coefficient between press being applied on human body and press being applied on dog body. \( \alpha_1, \alpha_2, \beta_1 \) and \( \beta_2 \) separately represent lateral images captured on different angles. \( l_{ij} \) represents section diameter of fracture, \( i \) represents team numbers, \( j \) represents different capturing angles[4].

6. Conclusion

The intelligent setting system for fracture is based on digital image processing and pattern recognition technology. The wound caused by setting is not only very small, probability of fracture nonunion and delayed union is but also greatly reduced. Level of fracture setting is first heightened to automatic setting stage from experience and sense stage. Development and application of the system lay the solid foundations in theory and practical experiments for development of fracture intelligent diagnosis and treatment system and telemedicine fracture setting system [5].

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