The Study Of Multifunction External Fixator Based On Stewart Platform

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Abstract. The article develops the model of bone deformities, making 6-DOF Parallel Mechanism have widely applied to correction of deformities. The platform's positional direct solution is the posture of the motion platform. Malformation can be measured by X-ray, based on the space coordinate transformation can find the final posture of the motion platform. Regarding the reverse solution to platform kinematics the paper gives a quick arithmetic program, six actuators to realize motion requirements. For the computer-assisted fracture reduction, we produced an application interface.

Keywords: 6-DOF; parallel; positional direct solution; numerical method

1 Introduction

Stewart platform is a kind of 6-DOF parallel mechanism, which has a stable and compact structure and high precision[1-3]. It is very suitable for those work situation where the work space is limited or the work space is not large enough but the load is very heavy[4].

Fig.1 shows the femur correction process in use of Stewart platform. Firstly, doctors install the fixation frame through operation: first, put the bone blocks where the two ends of the site to be corrected fixed in

the upper and lower platforms, then the platform's translation or rotation can drive the corresponding bone block translating and rotating, as shown in Fig.1A; second, install the 6 studdles and tighten them, making them in the state of unadjustable, as shown in Fig. 1B. Secondly, use X-ray film to measure the corresponding parameters, then put the parameters into Computer-Aid Software and get the lengths of the 6 studdles. Doctors can accomplish the orthopedic by rotating regulating nut to realize the elongation or decurtation of the 6 studdles, as shown in Fig 1C.

Fig 1.Femur correction diagram

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Because of the particularity in structure of the Stewart platform, it is needed to regulate 6 studdles simultaneously in order to accomplish the movement of single degree of freedom[5]. However, if doctors make adjustment only depend on the subjective experience, it will be almost impossible to reach the goals, and even leading to more severe malformation. This paper studies on the Stewart platform Compliance and Multifunction External Fixator corresponding software.

2 Modelling

We definite two coordinate systems, which are socle coordinate {B} and upper platform {P}. The origin of the socle coordinate {B} is located in the center of the socle O_b , and the center of the upper platform O_p is the origin of the upper platform coordinate {P}, as shown in Fig.2.

Fig 2. The definition of space

Set the moving platform {P} rotates the angle of γ along X_b axis, β angle along Y_b axis and α angle along Z_b axis. Then we obtain the transfer matrix on coordinate {B} along three axes in use of aforesaid definition.

$$R = \begin{bmatrix} c\alpha \cdot c\beta & c\alpha \cdot s\beta \cdot s\gamma - s\alpha \cdot c\gamma & c\alpha \cdot s\beta \cdot c\gamma + s\alpha \cdot s\gamma \\ s\alpha \cdot c\beta & s\alpha \cdot s\beta \cdot s\gamma + c\alpha \cdot c\gamma & s\alpha \cdot s\beta \cdot c\gamma - c\alpha \cdot s\gamma \\ -s\beta & c\beta \cdot s\gamma & c\beta \cdot c\gamma \end{bmatrix}$$

$$= \begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix} \quad (1)$$

Where $c\alpha = \cos \alpha$, $s\alpha = \sin \alpha$, $c\beta = \cos \beta$, $s\beta = \sin \beta$,

$c\gamma = \cos \gamma$, $s\gamma = \sin \gamma$. We obtain the length of the studdle from Fig.2.

$$l_i = |\overline{B_i P_i}| = |\overline{O_b O_p} + R \overline{B_i O_p} - \overline{O_b B_i}| \quad i = 1, 2, \dots, 6 \quad (2)$$

Therefore, if we obtain the position vector $[X_p \ Y_p \ Z_p]^T$ and the vector of attitude angle $[\alpha \ \beta \ \gamma]^T$ of the moving platform after orthopaedic, we can get the final lengths of six studdles by Eq.1. Firstly, put the six independent equations in Eq.2 into three groups i.e. (l_1^2, l_6^2) , (l_2^2, l_5^2) and (l_3^2, l_4^2) , then we carries out the calculation of addition or subtracting between the two equations in one group and obtain six independent equations in other forms. Expand each term in the equation and make use of relations as follows:

$$\left. \begin{aligned} d_{11}^2 + d_{21}^2 + d_{31}^2 &= 1 \\ d_{12}^2 + d_{22}^2 + d_{32}^2 &= 1 \\ d_{11}d_{21} + d_{21}d_{22} + d_{31}d_{32} &= 0 \end{aligned} \right\} \quad (3)$$

Then we get six independent equations as follows

$$\begin{aligned} \frac{l_1^2 + l_6^2}{2} &= R_p^2 + R_b^2 + W - 2Y_p B_{1Y} - 2(d_{11}P_{1X}B_{1X} + d_{22}P_{1Y}B_{1Y}) + 2P_{1Y}(D_2 \bullet P) \\ \frac{l_1^2 - l_6^2}{4} &= -X_p B_{1X} - d_{21}P_{1X}B_{1Y} - d_{12}P_{1Y}B_{1X} + P_{1X}(D_1 \bullet P) \\ \frac{l_2^2 + l_5^2}{2} &= R_p^2 + R_b^2 + W - 2Y_p B_{2Y} - 2(d_{11}P_{2X}B_{2X} + d_{22}P_{2Y}B_{2Y}) + 2P_{2Y}(D_2 \bullet P) \\ \frac{l_2^2 - l_5^2}{4} &= -X_p B_{2X} - d_{21}P_{2X}B_{2Y} - d_{12}P_{2Y}B_{2X} + P_{2X}(D_1 \bullet P) \\ \frac{l_3^2 + l_4^2}{2} &= R_p^2 + R_b^2 + W - 2Y_p B_{3Y} - 2(d_{11}P_{3X}B_{3X} + d_{22}P_{3Y}B_{3Y}) + 2P_{3Y}(D_2 \bullet P) \\ \frac{l_3^2 - l_4^2}{4} &= -X_p B_{3X} - d_{21}P_{3X}B_{3Y} - d_{12}P_{3Y}B_{3X} + P_{3X}(D_1 \bullet P). \end{aligned} \quad (4)$$

$$D_1 = \{d_{11}, d_{21}, d_{31}\}^T, D_2 = \{d_{12}, d_{22}, d_{32}\}^T, W = X_p^2 + Y_p^2 + Z_p^2.$$

After element elimination, there are three unknown quantities X_p , Y_p , Z_p in the six equations, besides, each direction cosine has been denoted by the function of X_p , Y_p , Z_p . Thus, if the lengths of six studdles (i.e. inputs) $l_i (i=1,2,\dots,6)$ are given, we can adopt optimization theory to solve this equation system, and obtain the initial position and pose of the upper platform.

Therefore, according to the malformation parameters and the installation framework parameters which are measured by doctors, we obtain the final position vector in use of coordinate frame and get the final lengths of six studdles through Eq.2.

3 Bone model experiment

Fig 3. Shows the demonstration framework of malformation model of left femur. We can read the lengths of six studdles as follows: 180mm, 184mm, 169mm, 168mm, 190mm, 197mm. Through shooting orthophoria, we obtain the malformation parameters as follows: valgus 10° , medial displacement 12.9mm. Besides, we get other malformation parameters from the side position image as follows: flexion 10° , anterior displacement 15mm, overlength 11mm. The installation parameters are as follows: the center of the ring is located in 5mm in front of the initial point, and breakpoint is 65mm to the proximal femur. Then put the aforeside parameters into the software, and we can obtain the treatment prescription. According to the final frame, we adjust the lengths of six studdles as 166mm, 178mm, 173mm, 167mm, 158mm, 162mm. Fig 4. shows the efficacy of orthopaedic.

Fig 3a. Orthophoria image

Fig 3b. Lateral image

Fig 4. The framework after orthopaedic

4 Clinical operation

As shown in Fig 5., the bone of Miss Jing's left tibia is disjunct and has an angular deformity. Fig. 6. shows the X-ray of orthophoria and lateral, after the measurement, we can obtain the distortion parameters: varus 50° , flexion 30° , internal rotation 25° ; installation parameters: proximal ring and distal ring are full-circular with a diameter of 155mm, the framework has a deviation of 10.8mm to medial starting point, a deviation of 46.2mm to posterior starting point, the axial deviation is 80.0mm, and the external rotation of the framework is 15° ; the initial lengths of six studdles are 178mm, 190mm, 166mm, 147mm, 127mm, 145mm. Put these parameters into the software and obtain the final lengths: 148mm, 111mm, 200mm, 209mm, 219mm, 148mm. After some model experiments, the error rate of continuous orthopaedic reaches 3mm and $<1^\circ$.

Fig 5.Before the operation

Fig 6.X-ray of the patient after installing Fixed frame

Fig 7.After the operation

5 Conclusion

Through the experiment of bone model, we can see the efficacy of disposable reduction is advisable. But because of some external factors such as patient's movement and so on, in order to reach the best efficacy, doctors should shoot X-ray after a period of time, remeasure distortion parameters, make a rejigger for

treatment prescription, and use a method of continuous correction to minimize the deviation.

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References

- [1] Zhen Huang: *Spatial Kinematics*. (China Machine Press, In Chinese, 1991)
- [2] Guanglan Xia, Xiaoping Hu, and Caihua Li. China Science and Technology Information, vol.22, pp.28. (In Chinese, 2005)
- [3] Zhen Huang, Yongsheng Zhao, and Tieshi Zhao: *Higher Spatial Kinematics*. (Higher Education Press, In Chinese, 2006)
- [4] Jin Xie, and Yong Chen. Mechanical Science and Technology for Aerospace Engineering, vol.29, pp.524-526. (In Chinese, 2000)
- [5] Xiangguo Han, Wuyi Chen, and Dingchang Chen. JOURNAL OF BEIJING UNIVERSITY OF AERONAUTICS AND ASTRONAUTICS, vol.28, pp.370-372. (In Chinese, 2002)