A development of the automated system for adjusting the 6 D.O.F circular fixator

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Abstract: In this article, we present the development of the automated system for adjusting the 6 D.O.F circular fixator. The system includes scheduling software to adjust the Hexapod Circular Fixator (HCF) and an automated strut system with the ability of the multiple synchronized motion. HCF was designed to control a 6 degree-of-freedom Ilizarove fixator and it's mechanism is known as the Stewart Platform. HCF scheduler evaluates each value of altered length of the HCF struts to correct the complex skeletal deformity by using the X-ray data of the patient. The data of HCF scheduler feed into the automated strut system which be able to provide the scheduled adjustment and the automated strut is synchronized by input data.

Key Words : Automated system, Hexapod Circular Fixator (HCF), Scheduler, Stewart Platform, The automated strut

1. INTRODUCTION

The distraction lengthening is based on principle of osteogenesis by activating the tissue of skin, muscle, nerve and vessel in the body. Generally, the distraction lengthening applies to fixators which are grouped into external and internal ones [1, 2].

The Hexapod Circular Fixator (HCF), a kind of 6 D.O.F circular fixator comprise of two rings and six struts. The 6 struts are installed on the skew between the two rings. This type of parallel mechanism is known as the Stewart Platform. The Stewart Platform is useful for an complicated angular transformation. Fig 1

Fig. 1 The Hexapod Circular Fixator (HCF)

In this article, we studied the automated system for the adjusting HCF. The automated system for the adjusting HCF is composed of HCF scheduler and automated struts.

Because of the complexity of framework analysis, it is hard to know intuitively that frame is changed when the lengths of the struts are changed. So we've developed the HCF scheduler. The HCF scheduler helps to know easily change of lengths with the passage of time. We've studied automated strut system which can adjust the lengths of the strut by using the calculated data from HCF scheduler.

2. KINEMATIC ANALYSIS OF THE 6 D.O.F CIRCULAR FIXATOR

The system of the 6 D.O.F circular fixator has the same mechanism as the Stewart Platform. The basic kinematic equation is the same as that the Stewart Platform. The kinematic equation of the relationship between lengths of the struts and bone is found by the basic kinematic equation. This kinematic equation acts as a basis of the development of the HCF scheduler.

The characteristics of the HCF can be modeled as shown in Fig. 2.

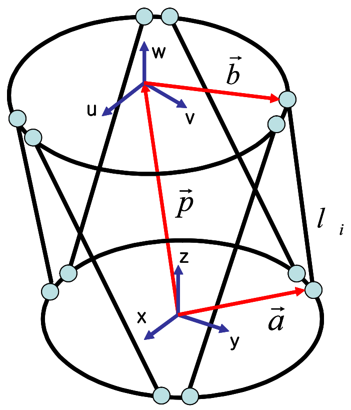


Fig. 2 HCF Geometry

Let u, v, and w be three unit vectors; then the rotation matrix can be written as Eq. (1)

$$R = \begin{bmatrix} u_x & v_x & w_x \\ u_y & v_y & w_y \\ u_z & v_z & w_z \end{bmatrix} \tag{1}$$

So we can get a vector-loop equation for the i-th limb of the manipulator as follows Eq. (2)

$$\vec{l_i} = \vec{p} + R\vec{b_i} - \vec{a_i} \quad (2)$$

Also the length of the i-th limb is obtained by the Eq (2). It can be written as Eq. (3)

$$l_i = \sqrt{\left(\vec{p} + R\vec{b_i} - \vec{a_i}\right)^T \left(\vec{p} + R\vec{b_i} - \vec{a_i}\right)} \quad (3)$$

As shown in Fig. 2, position vector $\vec{P}$ is the transformation from the moving platform to the fixed base. And $\vec{a_i}$ and $\vec{b_i}$ are the position vectors of points A_i and B_i in the coordinate frames A and B. Also l_i is the length of each struts.

The basis equation of the relationship between lengths of the strut and bone is obtained by Eqs (1) ~ (3). The characteristics of the relationship between struts and bone can be modeled as shown in Fig. 3.

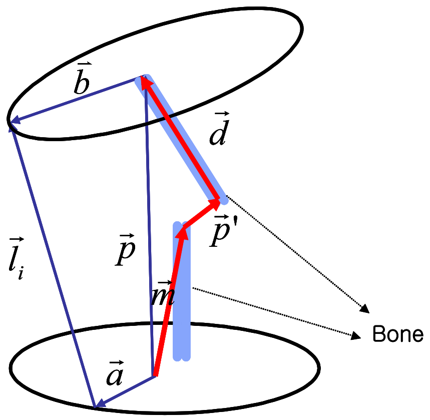


Fig. 3 Schematic Modeling of the HCF and Bone

As shown in Fig. 3, vector $\vec{m}$ is the transformation from the center of fixed base to the end of reference bone. And vector $\vec{d}$ is the transformation from the center of moving ring to moving bone. Also vector $\vec{p'}$ is the transformation from reference bone to moving bone. So we can get a vector $\vec{p}$ equation as follows Eq. (4)

$$\vec{p} = \vec{m} + \vec{p'} + R\vec{d} \quad (4)$$

The equation of the relationship between lengths of the strut and bone is obtained by Eqs (1) ~ (4). It can be written as Eq. (5)

$$l_i = \sqrt{\left(\vec{m} + \vec{p'} + R\vec{d} + R\vec{b_i} - \vec{a_i}\right)^T \left(\vec{m} + \vec{p'} + R\vec{d} + R\vec{b_i} - \vec{a_i}\right)}$$
(5)

This equations act as a basis of the development of the HCF scheduler. [7-10]

3. THE AUTOMATED SYSTEM

The automated system includes scheduling software to adjust the Hexapod Circular Fixator (HCF) and an automated strut system with the ability of the multiple synchronized motion.

3.1 HCF scheduler

HCF scheduler is consisted of two algorithms operation which are initial deformity correction and remaining deformity correction. The initial deformity correction is basic deformity correction mode. This is correction mode for inserting the value before the correction of deformity, so that make it possible to correct up to the neutral position when finished each correction. The remaining deformity is also correction mode in order to correct finally its error up to expecting position after initial deformity correction.

The interface of HCF scheduler is consisted of three parts- input, output and save.

- Parameter input parts

The parameters for patient, frame, deformity and mounting are obtained from corresponding windows for each parameter.

The database is build of name, age, number, birth and date of surgical operation obtained from patient window, Fig. 4

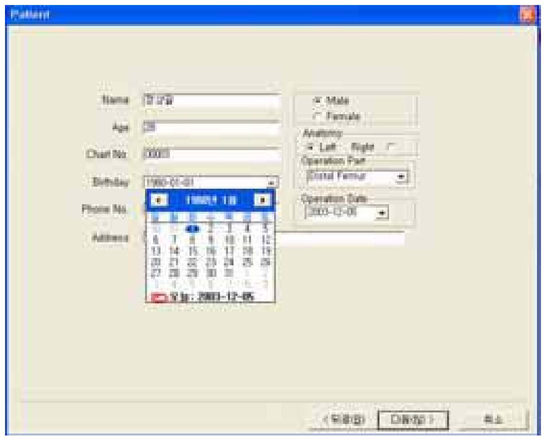


Fig. 4 Window for patient data input

The input for frame data is build of size of proximal ring and distal ring obtained from ring size window, Fig 5. And it is build of arrangement angle of joint adaptor, Fig. 6

Fig . 5 Window for proximal ring and distal ring size

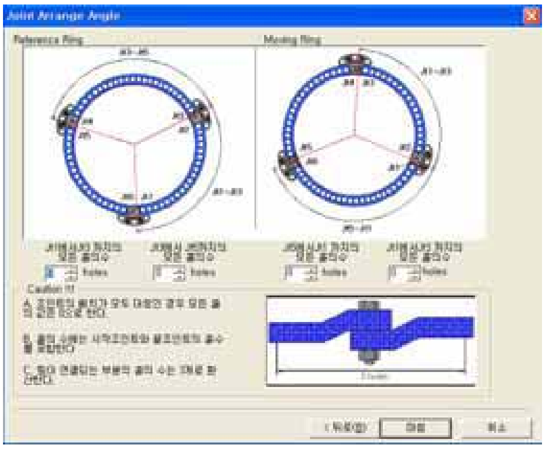


Fig. 6 Window for arrangement angle of joint adaptor

The data for deformity and mounting parameter is build of position deformity, angle deformity and offset of anterior posterior (AP), lateral and axial direction obtained from deformity and mounting parameter window, Fig. 7.

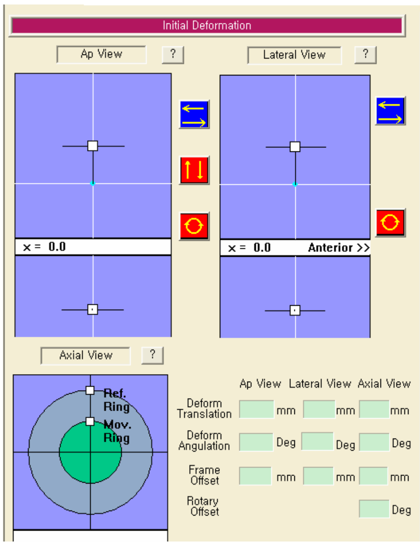


Fig. 7 Window for deformity and mounting parameter

The terms of deformity correction is build of initial deformity correction or remaining deformity correction decided on deformity correction window, Fig. 8

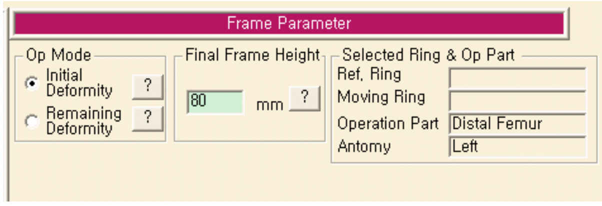


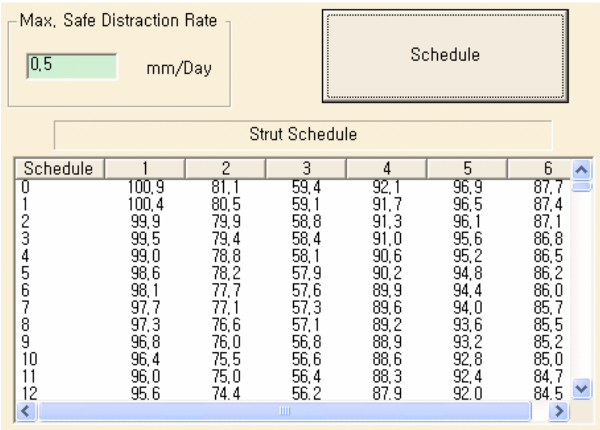
Fig. 8 Window for deformity correction

- Parameter save part

The parameter save parts is save up database consisted of each patient data. It can be easy to get information of patient data (name, birth, age, etc), the region of surgical operation, final result of initial / remaining deformity correction, etc.

- Parameter output part

The parameter output part shows the data of database on the computer monitor, Fig. 9. The deformity correction of a day is decided by total deformity correction. The decided deformity correction of a day is saved up database. And the saved data of database communicates itself to controller of the automated system. And the automated strut is run by controller of automated system.



Schedule	1	2	3	4	5	6
0	100.9	81.1	59.4	92.1	96.9	87.7
1	100.4	80.5	59.1	91.7	96.5	87.4
2	99.9	79.9	58.8	91.3	96.1	87.1
3	99.5	79.4	58.4	91.0	95.6	86.8
4	99.0	78.8	58.1	90.6	95.2	86.5
5	98.6	78.2	57.9	90.2	94.8	86.2
6	98.1	77.7	57.6	89.9	94.4	86.0
7	97.7	77.1	57.3	89.6	94.0	85.7
8	97.3	76.6	57.1	89.2	93.6	85.5
9	96.8	76.0	56.8	88.9	93.2	85.2
10	96.4	75.5	56.6	88.6	92.8	85.0
11	96.0	75.0	56.4	88.3	92.4	84.7
12	95.6	74.4	56.2	87.9	92.0	84.5

Fig. 9 Window for parameter output part

3.2 Automated strut

The automated strut needs actuator for operating fixator. But general actuator has revolute motion. So actuator converts rotation into linear motion for using automated strut.

The type of external fixator is grouped into telescope type and screw type. The automated sturt is making use of screw type strut for converting rotation into linear motion and precision motion. Also the automated struts is making use of stepping motor as a actuator.

The strut needs precision control and enough torque for resisting the load of a patient. Also the strut's laod and size have to decrease for patient. All things considered, the automated strut is designed.

The type, size, pitch, lead of screw have to consider in order to select screw. The determinate screw has lead of 1mm, that is, pitch is 1mm. Therefore the screw runs 1mm per one turn.

As mentioned above, the strut needs precision control and enough torque for resisting the load of a patient. A supported ideal load of one strut is about one of twelve of the load of a patient because a load of patient is divided by the number of total struts and the number of legs. The equation of the relationship between the strut and supported load of strut is obtained by Eqs (6) ~ (8).

$$P_S = \frac{P_H}{6} \tag{6}$$

$$P_H = \frac{W}{2} \tag{7}$$

$$\therefore \quad P_S = \frac{W}{12} \tag{8}$$

$P_S =$ Supported load of one strut

$P_H =$ Supported load of HCF

$W =$ Load of patient

If load of a patient is 80 kgf, supported load of a strut is below 7 kgf. But design of the strut considers not only a load of patient but also load of external constituents - muscle power, being angle of axis direction, etc.

Also load and size of strut have to decrease for patient. The automated strut is designed to disjoint an actuator from the automated strut. And selected actuator operates in low velocity and enough torque because the fixator have to have safety and precision, Fig. 10.

Fig. 10 The Automated strut

The velocity of automated strut is 1mm/sec and maximum load of automated strut is 200kgf. . So we designed the automated strut as follows Table. 1.

Table. 1 Criterion of Design

	Contents	Remarks
Load of Axial direction	About 120kgf	per one strut
Operator Velocity	1mm/s	velocity of strut
Operator Voltage	12V	DC
Sensor	encoder	

3.3 Control of the automated strut

In the automated strut system, controller processes data of the scheduler and adjusts lengths of automated struts. As shown in Fig. 11, the automated strut system calculates the data on the HCF scheduler and move expecting lengths of struts as inputting the date processed by the controller, at the result, it can move the HCF as expectation.

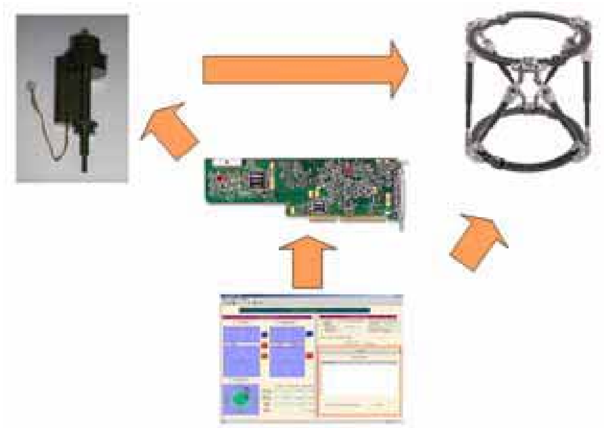


Fig. 11 Control of the automated strut

Each strut can move not only independently but also synchronously.

The automated struts move expecting lengths of struts as schedule data of one day. The automated struts don't move at a time for safety of patient. The schedule of one day is devided into as many segments of motion data as form 15 up to 720 and the automated struts move deviding lengths of struts.

The operation of struts follows status. 'Stand-by', 'Data distribution', 'Motion start', 'In-motion' and 'Result check'.

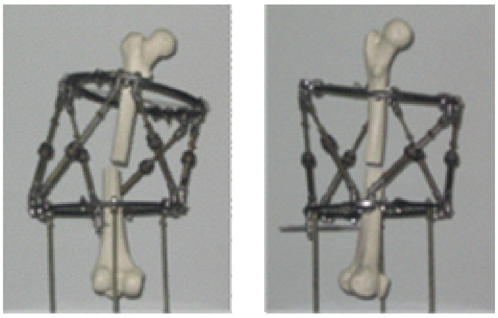
4. EXPERIMENTS & RESULTS

4.1 Experiments

This experiment for the HCF operateing system is used with model bone, and then that get a data based on scheduler. At the first, to put the data from using the model bone into a HCF scheduler. Output data from the latter also put it into automated controller so it can make to move the motion of struts.

In order to confirm the error of the HCF scheduler, real model was used for verification. The data from HCF scheduler apply to the automated strut, and then we confirm error of the automated strut.

Fig. 12 is picture of pre-operation and the experiment is progressed with data of Fig. 12



AP view Lateral view

Fig. 12 Pre-operation

4.2 Results

Fig. 13 is the scheduler data sheet and it is a data from using the model bone into a HCF scheduler.

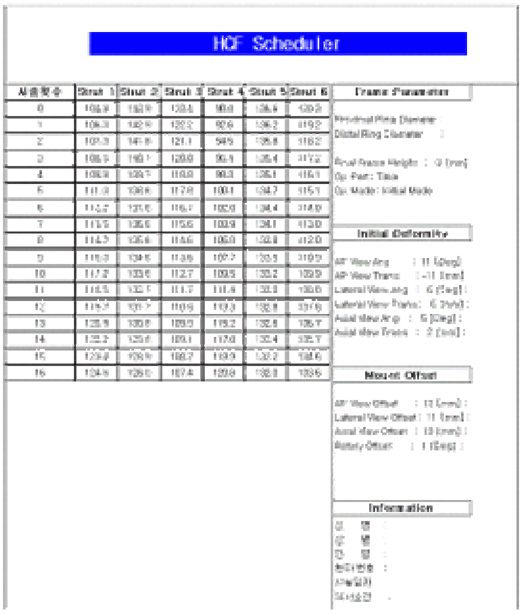
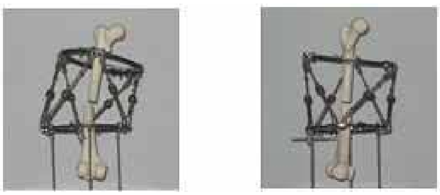
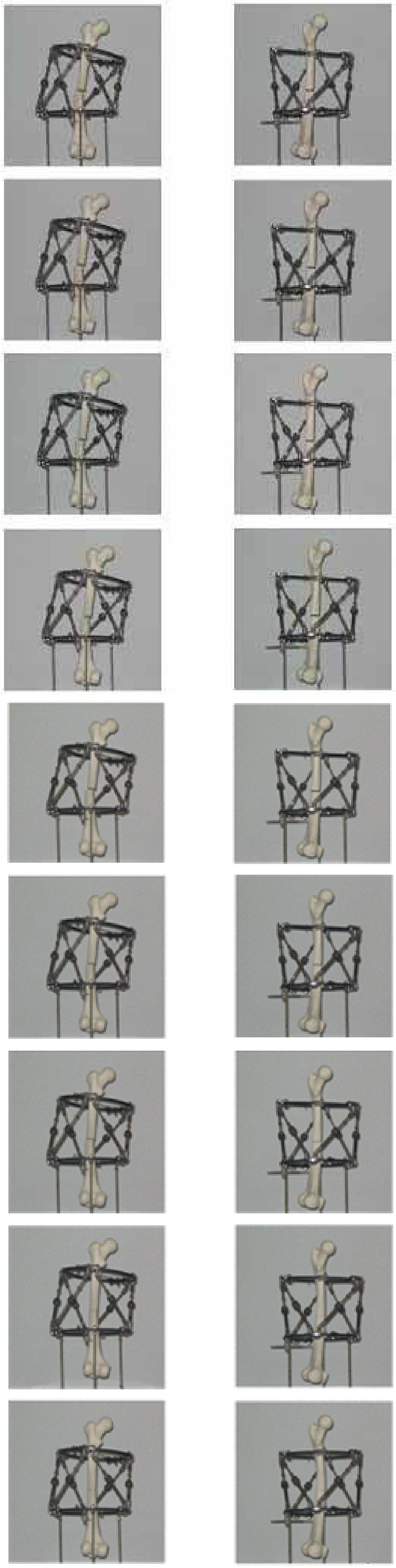


Fig. 13 HCF scheduler data sheet

We experimented with applying HCF from the data of scheduler data sheet. Fig.14 is result of experiment.

Ap view Lateral view

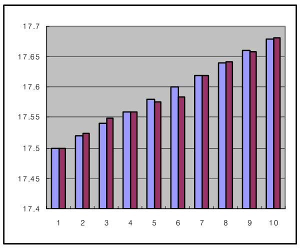




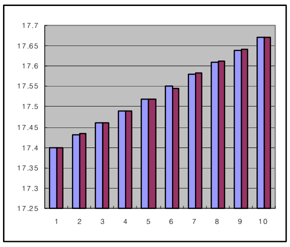
Filg. 14 Post–operattion

The result of experiment indicated property of the HCF scheduler.

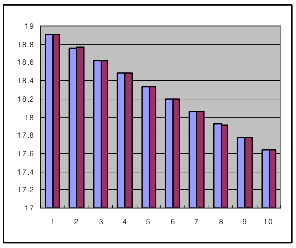
The experiment of automated strut uses data of the Fig.14 and Fig. 15 is graph of the result of experiment.



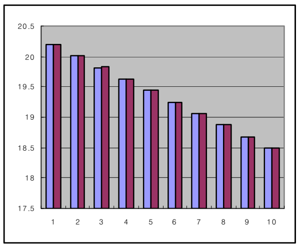
Strut 1



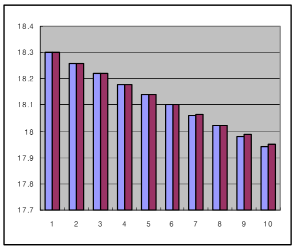
Strut 2



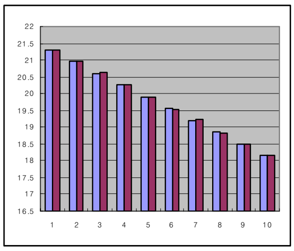
Strut 3



Strut 4



Strut 5



Strut 6

Fig.15 Graph of the result of experiment

Fig.15 shows that error occurs somewhat randomly and accumulative error did not increase.

5. CONCLUSION

The proposed automated system focuses on the ability of precision and useful motion. The scheduler itself was verified to get procise data by using the existing HCF, the 6 D.O.F circular fixator. The automated strut also was verified by experiment.

Finally we verified properties of the HCF automated system. However before using the HCF automated strut system, we have to verify through clinical demonstration.

6. ACKNOWLEDGEMENTS

This work was supported by grant No. Ro1–2003–000–11635-0 from the Basic Research Program of the Korea Science & Engineering Foundation.

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