Fuzzy Determination of Anatomical Reference Points in 3D Kinematical Measurement for Human Body

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Abstract— **Three-dimensional (3D) kinematical measurement is important for the clinical assessment of kinematics of injury parts of human body. This measurement needs reference points of injury parts for estimating kinematics. In general, the reference points were pointed by an operator using a probe. However, there is a problem which the reference points strongly depend on feeling of the operator. This is why the large deviation of determined reference points. This study aims to reduce the deviation of reference points by introducing a reliability of operator and a characteristic of shape of reference points. In the experiment, the conventional method and the proposed method were applied for two reference points (the medial and lateral epicondyles) of two knees of one subject operated by a beginner and an expert. The deviations of the conventional method and the proposed method in case of the beginner were 33.89 mm and 4.38, respectively. Consequently, the proposed method reduced the deviation of determined reference points.**

I. Introduction

In orthopeadic surgery, total knee arthroscopy (TKA) has been increasing recently. Hence, importance of measurement of kinematics of knee has been focused on. After TKA surgery, surgeons usually evaluate the repair knee subjectively for anatomical criterion (e.g., flexion/extension, abduction/adduction, external rotation/internal rotation., etc.). Conventional methods used X-ray CT scanner, but it is not kinematical data.

Mahfouz, et. al. have reported the assessment of knee kinematics for patients with a hamstring or patellar tendon ACL graft by using video fluoroscopy in post operation [1][3]. Moreover, they have reported a robust method for registration of three-dimensional knee implant models to two-dimensional fluoroscopy images. This method employs fluoroscopy images and implant models to evaluate the knee kinematics. Although this method has the advantage of measurement accuracy, large equipment and information of implant models is needed for fluoroscopy images. In addition, we have to point out the radiation exposure.

J. F. Suggs, et. al. have reported function of the anterior cruciate ligament after unicompartmental knee arthroplasty [4]. This study examined the kinematics of human cadaveric knee by using robotic testing system. The proposed system needs to grasp the femoral and tibial bone by the robotic testing system directly. Hence, the accurate load was applied into the knee joint, but it cannot be applicable to the human body.

Several commercial systems by aided LED can provide such information precisely, however they needs to implant pins for femur and tibia bone directly [2]. From this reason, it can be applicable for subjects in intra-surgery, not in pre- and post- operation. To overcome these problems, we developed the measurement system for knee kinematics by using electromagnetic sensor for measuring in also pre- and post- operation. Here, J. Y. Jenny, et. al. have reported low reproducibility of the intra-operative measurement of the transepicondylar axis during total knee replacement by using image analysis system [5]. They pointed out low reproducibility the reference points obtained by operator. In the experiment, two surgeons defined the transepicondylar axis 3 times each without changing the reference plane. In the results, the mean intra-observer ranges of variation were about 5 degree with a maximum 15 degree. The mean inter-observer range of variation was 9 degree, with a maximum of 15 degree.

This paper proposes a determination method of anatomical reference points used for kinematical measurement of the knee. The conventional method has large deviation of reference points by ignoring human error. Here, this paper proposes a concept of reliability of operator which controls dependency of determined reference points for feeling of an operator. In addition, characteristic of reference points which has complementary relation with reliability, is feasible to determine reference points. Fuzzy logic is employed to deal with these information. Fuzzy logic proposed by Zadhe, is a powerful tool representing human knowledge [7][8]. Because there are a lot of vagueness representing in medical field, fuzzy logic is useful for us to realize that [9][10]. In the experiment, the lateral and medial epicondyles among reference points were estimated by the proposed method and the conventional method. As a result, the deviation of proposed method was smaller than the conventional method.

II. PRELIMINARY

A. Experimental System

We employed an electromagnetic sensor system (FASTRAK, Polhemus) to acquire three-dimensional kinematical data. This system consists of System Electronics Unit (SEU), one to four receivers and a single transmitter as

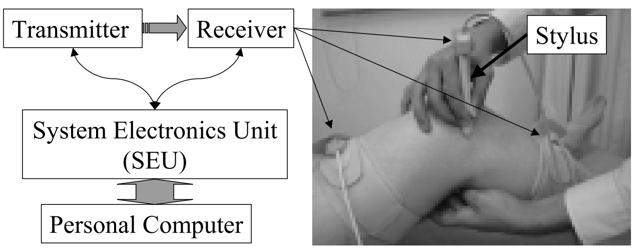
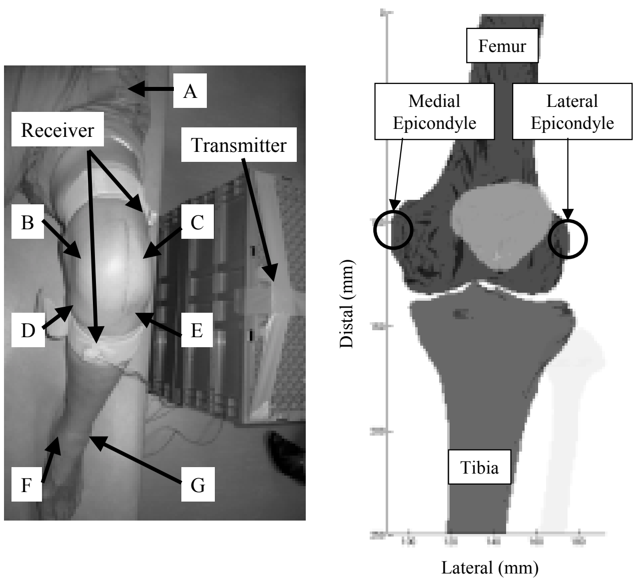


Fig. 1 Model of measurement device.

shown in Fig. 1. The transmitter radiates the electromagnetic wave, and the sensors received it. Different carrier frequencies allow operation of up to four FASTRAKs simultaneously and in close proximity to one another. The FASTRAK interfaces to a personal computer via RS-232 serial communication. By evaluating the carriers, the FASTRAK can provide information of the positions (i.e., X-, Y-, and Z- positions) and attitudes (i.e., Azimuth, Elevation, and Roll) of the receivers. The receivers were attached to the plastic braces located at the distal thigh and proximal lower leg.

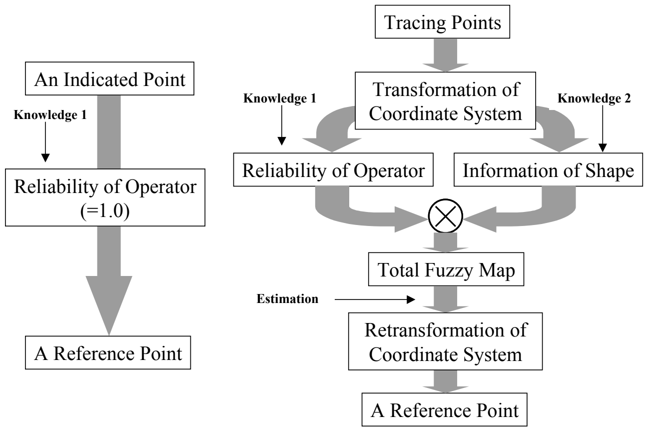
B. Reference Points

The anatomical reference points were digitized using a stylus equipped with an additional receiver before 6 DOF kinematical measurement. The reference points were (A) the greater trochanter of the femur, (B, C) the medial and lateral epicondyles, (D) medial edge of the tibial plateau, (E) the proximal edge of the fibula, (F) tibial tubercle and (G, H) the distal edges of the medial and lateral malleoli of the ankle (Fig. 2(a)). In acquiring the kinematics data, the reference points were calculated from position and attitude information of the receivers. Especially, this study focused on the medial and lateral epicondyles used for determination of medial-lateral



(a) Real situation (b) Bone model

Fig. 2 Reference points.



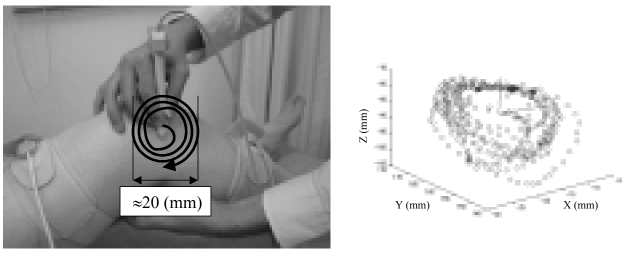
(a) Conventional method (b) Proposed method

Fig. 3 Determination procedure of reference points.

axis of the femur in assessment of knee kinematics [10][11]. Fig. 2(b) shows the reference points on a bone model. In the figure, the reference points are located as outer and inner apex of condyles. In the real situation, the position is unclear because the skin covers the region. In addition, it is hard to know the horizontal plane against the apex precisely. This is one of the reasons why the deviations of reference points occur.

III. Proposed Method

Determination procedure of reference points is shown in Fig. 3. In the conventional method, an indicated point equals to a reference point. This method expects that an operator indicate a reference point with high reliability. However, in real situation, large deviation occurs due to several factors such as human error and vagueness of definition of reference points. Here, this paper proposes a concept of reliability of an operator which provides a criteria of correctness of reference points by the operator. Characteristic of shape of



(a) Moving of stylus (b) Obtained data

Fig. 4 Tracing of reference point.

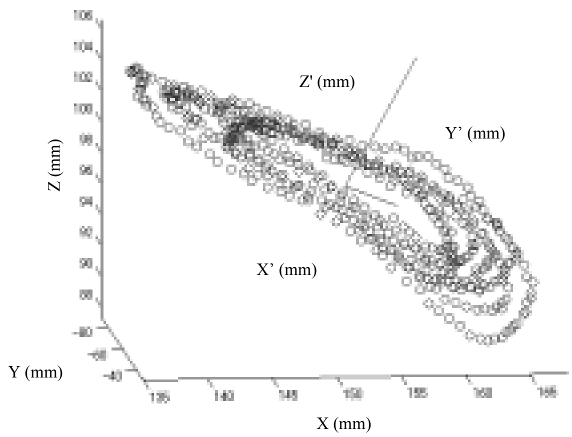


Fig. 5 A raw data.

reference point is used as complementary information of the reliability. In the proposed method, these information are calculated from tracing data around reference points. Fuzzy logic is employed to process these information.

A. Data Acquisition

Neighboring region within 20 mm around a reference point which was considered as a correct reference point, was traced by a probe during about 5 sec as shown in Fig. 4(a). Traced points obtained by the acquisition method imitate shape around a reference point as shown in Fig. 4(b). It is essential to transform the axes for calculation below process

B. Transformation of Coordinate System

New axes which consist of new coordinate system are calculated by principal component analysis. Because obtained data are three-vector, they have the first, second, and third principal components. Here, the new X-axis, Y-axis, and Z-axis are defined by the first, second, and third principal components, respectively as shown in Fig. 5. Figure 6 shows the transformed data by the axes.

C. Calculation of Fuzzy Map of Reliability

Reference points traced by an operator divergence due to human error. The conventional method uses the raw reference points by ignoring the human error. This paper introduce a concept of reliability of a operator. From an instruction, operators trace a constant region of a reference

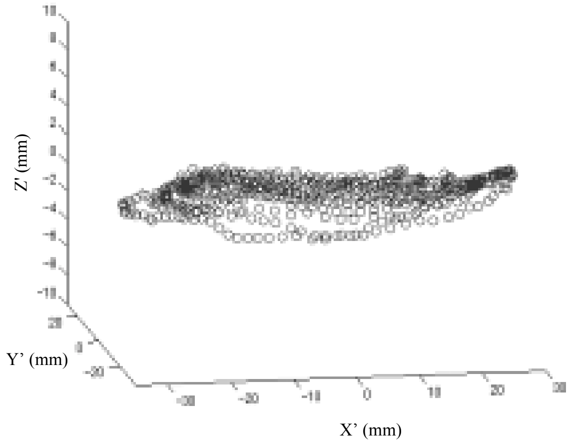


Fig. 6 Transformed data.

point centered by a point which is considered as the reference point. Therefore, we can derive following knowledge.

Knowledge of reliability:

Reference point is close to the center of tracing region.

This knowledge is interpreted as following fuzzy IF-THEN rule.

Rule of reliability:

IF a region is close to the center of tracing region,

THEN a degree of reference point is high.

From this rule, fuzzy map of reliability of operator is derived as follows.

$$F_{Reliability}(i, j) = \exp\left(-\frac{i^2 + j^2}{2\alpha}\right) \quad (1),$$

where $F_{Reliability}$ is a degree of reliability of operator. i, j are x-, and y- coordinates, respectively. α is a control parameter of this function. The control parameter has to be set larger value in case of low reliability. This paper used 20.0 as the control value. Fig. 7 shows a fuzzy map of reliability of Fig. 6. In this figure, a whiter pixel indicates higher possibility of reference point.

D. Calculation of Fuzzy Map of Shape

In view point of shape, a characteristic of reference points of epicondyles is considered as an apex of epicondyles. Therefore, we can derive following knowledge.

Knowledge of shape:

An apex of epicondyle is higher than neighboring region.

This knowledge is converted into Fuzzy IF-THEN rule as follows.

Rule of shape:

IF a region is higher than neighboring region,

THEN a degree of reference point is high.

From this rule, we can make a fuzzy map of shape by following equation.

$$F_{Shape}(i, j) = \frac{data(i, j) - \min(data)}{\max(data) - \min(data)} \quad (2),$$

where data(i, j) is the z-coordinates of the transformed data at (x, y) = (i, j). max and min are the maximum and the minimum of the transformed data, respectively. Fig.8 shows a fuzzy map of shape by applying this equation into Fig. 6.

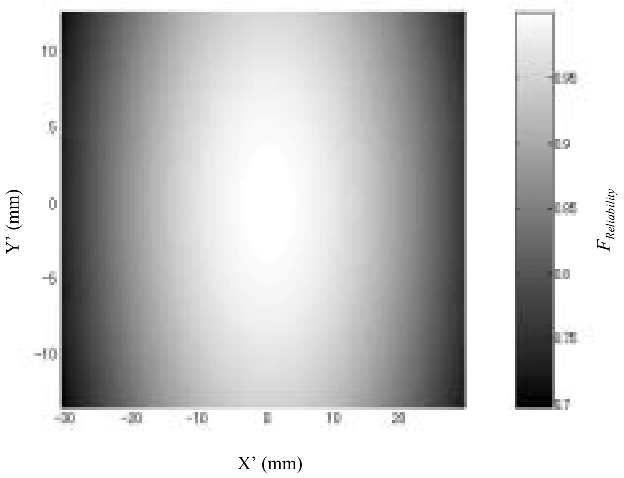


Fig. 7 A fuzzy map of reliability.

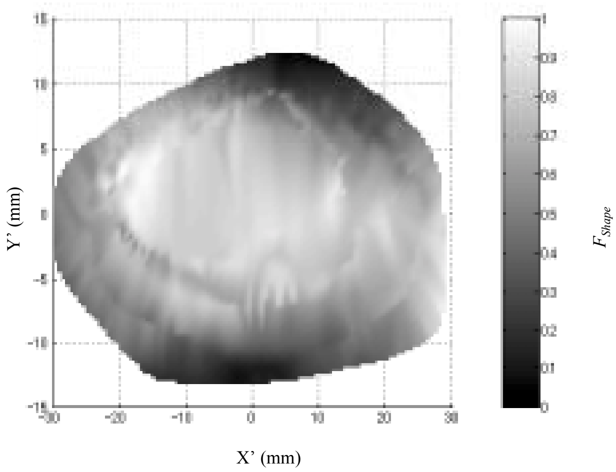


Fig.8 A fuzzy map of shape.

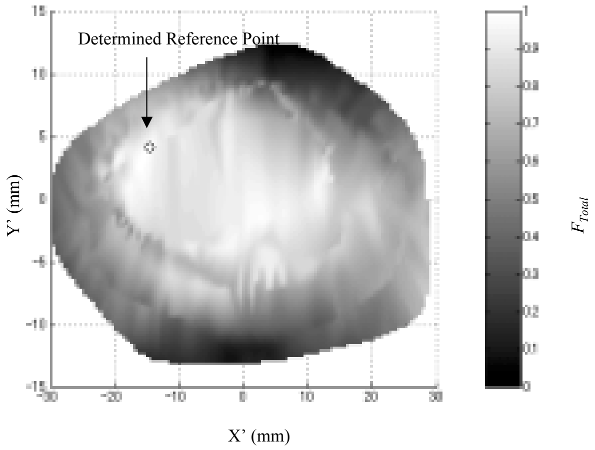


Fig. 9 A total fuzzy map.

TABLE I EXPERIMENTAL RESULTS.

Target	Conventional Method		Proposed Method	
	Beginner	Expert	Beginner	Expert
ME (Left)	29.718	11.272	4.462	3.516
LE (Left)	15.190	8.011	4.507	7.072
ME (Right)	53.282	7.860	2.870	1.946
LE (Right)	37.378	6.554	5.691	5.032
Mean	33.892	8.424	4.382	4.391

(ME: Medial Epicondyle, LE: Lateral Epicondyle, unit: mm)

E. Making Total Fuzzy Map and Estimating Reference Point

A total fuzzy map was calculated as following equation.

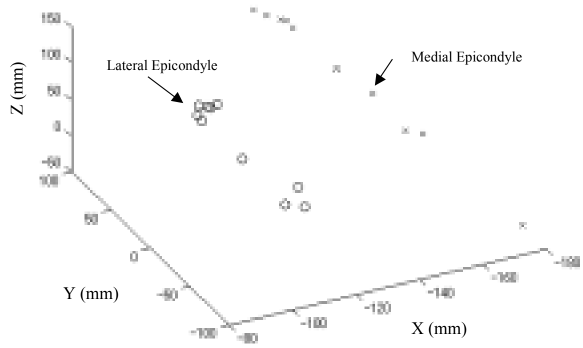
$$F_{Total}(i,j) = F_{Reliability}(i,j) \times F_{Shape}(i,j) \quad (3),$$

where F_{Total} is a total fuzzy degree. In this equation, × indicates an arithmetic product. Fig. 9 shows the total fuzzy map of Fig. 6. In this figure, a circle indicates the point with the highest degree of the total fuzzy map. The point is determined as the reference point.

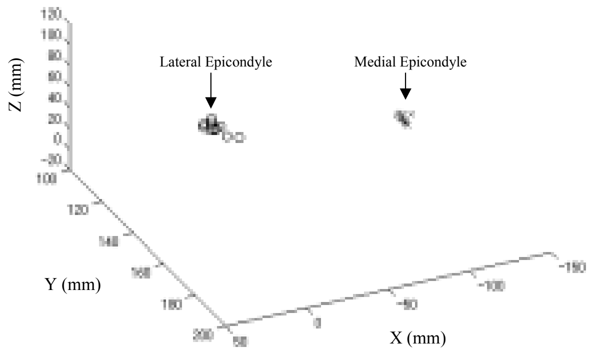
F. Retransformation of Coordinate System

Determined reference point is retransformed into original coordinated system with similar way of transformation of coordinate system. The retransformed reference point is used as a reference point for the knee kinematic measurement system.

IV. EXPERIMENT AND RESULT



(a) Conventional Method



(b) Proposed Method

Fig. 10 Examples of estimated results

The proposed method and the conventional method were applied into two knees of one subject who received informed consent. Both methods were operated by two examiner which were a beginner and an expert of this system. After providing instruction of tracing reference points, they traced shape around reference points during about 5 seconds. Each reference points were obtained with 10 trials.

Table I results the deviations of pointed reference points by the conventional method and the proposed method. In this table, the average of a set of reference pointsthe was used as the real value. The deviation of the distance between the real value and each reference points was calculated. The deviation of the proposed method decreased in comparison to the conventional method in case of a beginner and an expert. In addition, this table tabulates the deviation of the expert was smaller than the beginner.

Fig. 10 shows the examples of estimated results in case of the right leg examined by the beginner. In this figure, reference points of the proposed method convergence in comparison to the conventional method.

V. Conclusions

This paper proposed the estimation method of anatomical reference points used for knee kinematical measurement system. Reference points obtained by the conventional method strongly depend on the operator. Hence, the results varied from data to data. To overcome this problem, we introduced a concept of reliability of operator, and employed characteristic of shape as complement of it. In this paper, fuzzy logic was used to realize that. The proposed method and the conventional method were applied into the medial and lateral epicodyles operated by a beginner and an expert. As a result, divergence of the proposed method was smaller than the conventional method. In addition, this proposed method was meaningful for a beginner more than an expert. It reminds as a future work to apply the proposed method into other reference points.

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