On the Centrodes of Human Knee Joints using Photographic Method

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Abstract: The kinematics characteristics of the human knee joint can be represented by its centrodes. The sequential X-ray radiographs of the moving knee can provide the basic data for constructing the centrodes if the cost and side effects of radiation are not in concern. This paper provides an alternative method to construct the centrodes by using commercial digital camera to take the sequential pictures. In order to eliminate the undesired movements, a testing chair and a brace are specially designed. Two types of curve fitting methods are introduced to smooth the measured data of marked points on the lower leg. The differential method is applied to construct the centrodes of knee joint from the measured data. This paper provides a non-expensive, non-invasion, and non-radiation way to study the centrodes of human knee joint.

[Yingchien Tsai, Chengfeng Lin, Guangmiao. Huang, Hsienyuan. Lin. **On the Centrodes of Human Knee Joints using Photographic Method.** Life Science Journal. 2012;9(1):464-468] (ISSN:1097-8135). http://www.lifesciencesite.com. 69

Keywords Human Knee Joint, Centrodes, Polodes, Curve fitting, Photograph

1. Introduction

Total knee arthroplasty is one of the best choices for treating the severe osteoarthritis of knee which has been approved by the orthopedic community. The researches of knee arthroplasty have been focused on several topics like materials of artificial knee, design of artificial knee, manufacturing of artificial knee, surgical operation, and rehabilitation.

Nwoye et al. derived a model to calculate the concentration of upgraded iron for production of stainless steel based biomedical devices used in Orthopaedics [1]. The kinematics theories have been applied to study the biomechanics of human knee joints [2-3] and the performance of knee prosthesis [4]. Centrodes of four-bar linkage type knee prosthesis were studied by Menschik [5] and Van de Vee [6] . The centrodes have been also applied to study the characteristic of injured knee joints [7]. Lee and Chang developed the custom-made femoral stem by integrated investigation of CAD/CAM [8]. Lee et al. studied the rapid prototyping for the femoral component of knee prosthesis and by multi-axis NC Machining [9]. Shereif and Hassanin made a comparison between uses of therapeutic exercise and heat application on relieve pain, stiffness and improvement of physical function for patient with knee Osteoarthritis [10]. Tien and Yu found the Tai chi exercise affected the isokinetic torque but not changed hamstrings [11].

The centrodes of human joint can be constructed from a sequential X-ray radiographs of the moving knee. But the cost and side effects of radiation are bothersome. This paper aims to develop a non-expensive, non-invasion, and non-radiation way for people to study the centrodes of human knee joint.

2. Equipment Setup and Calibration

A Sony digital camera α55 equipped with 50~200mm lens is used for taking pictures of the human knee joints. It can take 10 high resolution pictures, 16.2 Mega pixels, per second. Since there exists the distortion problem in most of the commercial camera lenses, the accuracy checking and compensation processes of the photographs are required. A 1200mm x 90mm reference grid paper (Figure 1) is used for making correction of the photographs. In figure 1, the space between horizontal grid lines or vertical grid lines are 100mm and the increments of radii of the circles are 100mm.

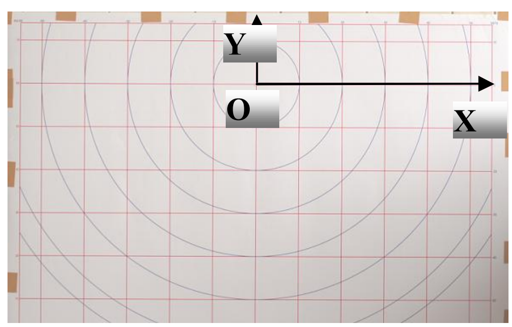


Figure 1. Reference grid for lens correction

The camera is set on a tripod aimed the center point of circles at right angle at distance 5,000mm away from the reference grid. The differences among the actual data and measured data from the captured photograph are shown in tables 1 and 2. Therefore the coordinates of a point in the photograph can be calibrated by using these tables.

Table 1. Correction data for X coordinates

Unit: mm

Dislocated coordinates of X		Actual Coordinates of X			
		-300	-200	-100	0
Actual Coordinates of Y	+100	-298.9	-199.2	-99.5	0.1
	0	-298.9	-199.4	-99.6	0.0
	-100	-299.0	-199.3	-99.5	0.0
	-200	-298.9	-199.3	-99.7	0.0
	-300	-299.0	-199.3	-99.6	0.0
	-400	-298.9	-199.3	-99.5	0.0
	-500	-298.7	-199.2	-99.6	0.0
	-600	-298.5	-199.2	-99.5	0.0
X ave		-298.8	-199.3	-99.6	0.0
average error		1.2	0.7	0.4	0.0

Table 2. Correction data for Y coordinates

Unit: mm

Dislocated coordinates of Y		Actual Coord. of X			Ave. error
		-300	-200	-100	
Actual Coordinates of Y	+100	100.0	100.1	100.1	0.2
	0	-0.1	0.0	-0.1	0.1
	-100	-100.2	-100.1	-100.2	0.0
	-200	-200.3	-200.2	-200.3	-0.1
	-300	-300.3	-300.3	-300.5	-0.2
	-400	-400.3	-400.2	-400.4	-0.1
	-500	-500.1	-500.2	-500.2	0.1
	-600	-599.7	-599.7	-599.8	0.4

3. Measurement of the Knee Motion

In order to eliminate the errors from the undesired movements, the upper leg is firmly wrapped on a special designed rigid chair as shown in figure 2. The foot and lower leg are firmly wrapped on a rectangular brace made of extruded aluminum beam. Three makers C, D, and E are set on the rectangular brace for tracing the movements of the lower leg, although from the kinematics point of view only the consequence coordinates of two points on a moving rigid body is required to determine the centrodes of this rigid body. There are two reasons for using three points. One can easily apply the homogenous coordinate techniques to calculate the displacement matrix. The other one is for double checking the experimental results. The loci of point C, D, and E are shown in figure 3.

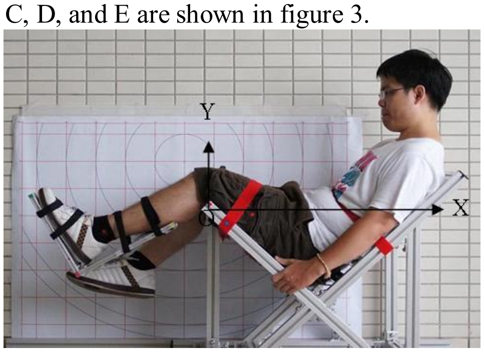


Figure 2. The testing chair and rectangular brace

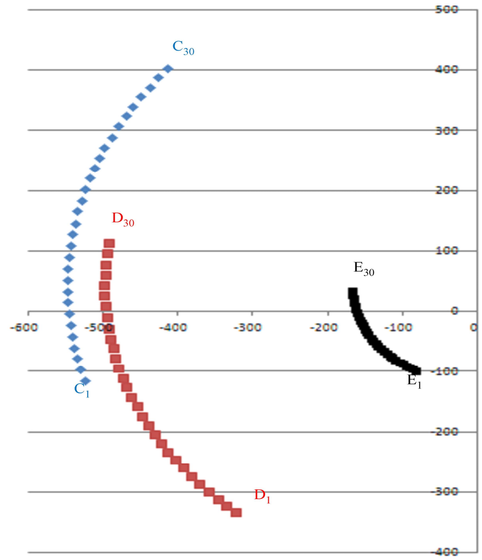


Figure 3. Loci of point C, D, and E

4. Determination of the centrodes

Two methods for determining the centrodes are demonstrated in this paper for comparison.

4.1 Finitely separated position method

The finitely separated position method is one of the commonly used methods in kinematics and industry practices. Draw the perpendicular bisectors of lines C1C2 and D1D2. The intersection point of these two perpendicular bisectors is a pole for position 1 and 2 as shown in figure 4. The loci of poles is called the polodes or called centrodes if the consequence points are very much closed to one others. This method is very easy to carry out, but it is very sensitive to the accuracy of coordinates of measurement points. The centrodes obtained by these methods is shown in figure 5. Obviously, the result is scattered and not acceptable. Therefore this method is not suitable in this study for determining the centrodes of knee joints.

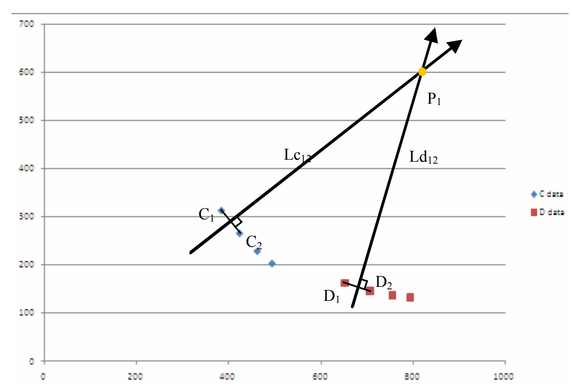


Figure 4. Finitely separated position method for finding the centrodes

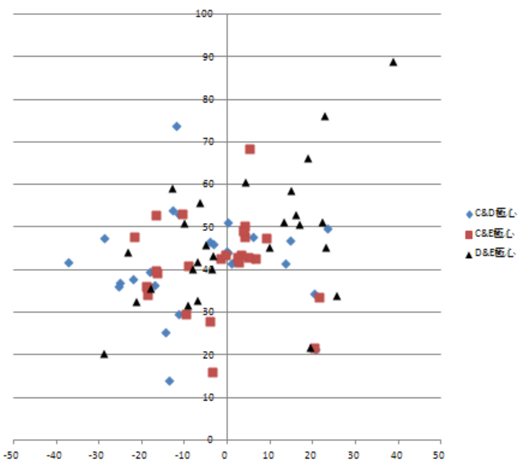


Figure 5. Centrodes using finitely separated position method

4.2 Differential Method

The loci of the marked points C, D, and E can be described as continuous functions by using curve fitting techniques. Although there are many types of curve fitting methods, only the polynomial function type and exponential function type are chosen for this study. For a planar curve described as a function y=f(x), the normal of this curve at point P (xi, yi) on the curve can be expressed as:

$$y = -x/y'(x_i, y_i) + k_i \qquad (1)$$

Where $y'(x_i, y_i)$ is the derivative of y respective to x at point $P(x_i, y_i)$, and k_i is a constant.

At any instance, the intersection of the normal of loci curve C at Ci(xci, yci) and of loci curve D at Di(xdi, ydi) is the instantaneous center as shown in figure 6. The loci of instantaneous center is the centrodes

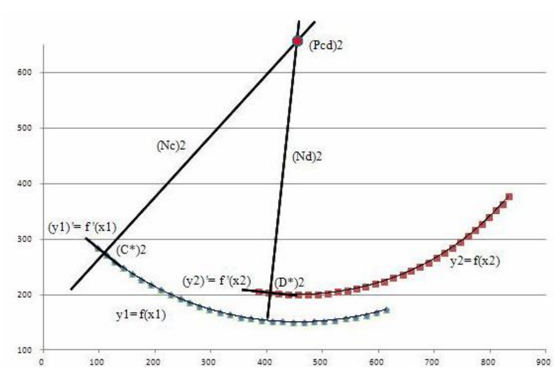


Figure 6. Differential method for finding the centrodes

Since the exponential function is applied to fit the measured data of marked point C, D, and E, no negative coordinates are allowed. Therefore before the curve fitting, all of the measured coordinates have to make a translation (-600, 500) followed by a rotation of 90° CCW. The parameters of fitting equations are shown in table 3 and table 4 for the polynomial type and exponential type respectively. Although the obtained curves by both methods fit the measured data very well, the one obtained by the exponential function is slightly better than the other one as shown in figure 7 and figure 8.

Theoretically from any two functions of lines of marked points C, D, and E can construct a centrodes. Practically, the combination of points D and E is not suggested, because the connecting line of C and D almost parallel to the tibia. Figure 9 and figure 10 show the centrodes constructed from curves C-D and C-E fitted by using polynomial function and exponential function respectively. Figure 11 is the comparison of all centrodes from both methods. Since it is very sensitive to the accuracy of measured data, there exists a variation around 5mm. This phenomenon may be improved by increasing the accuracy of measured data. as indicated by previous study as shown in figure 12 [2]. In order to give an idea of the actual dimensions of the centrodes, they are shown on the picture of a human knee joint in figure 13.

Table 3. Parameters of polynomial function

$$y = ax^4 + bx^3 + cx^2 + dx + e$$

	a	b	c	d	e
C	8.00E-10	1.58E-06	2.05E-03	1.18	3.81E+02
D	2.91E-09	-5.95E-06	5.59E-03	- 2.49	6.12E+02
E	2.78E-07	-5.64E-04	4.33E-01	-1.48E+02	1.97E+04

Table 4. Parameters of exponential function

$$y = a\exp(bx) + c\exp(dx)$$

	a	b	c	d
C	367	-0.003525	16.87	0.003343
D	370.4	-0.002402	13.47	0.003827
E	590.1	-0.0002757	0.008603	0.01591

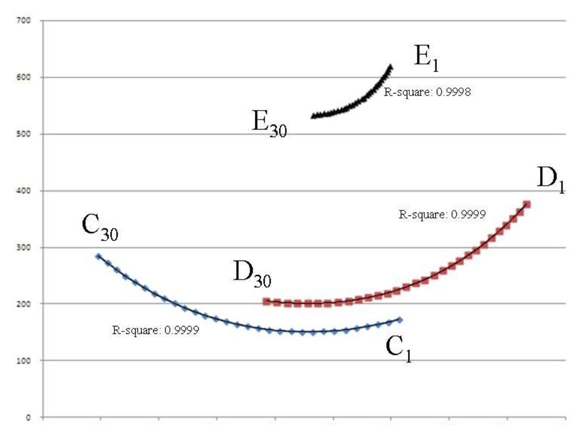


Figure 7. Curve fitting by polynomial function

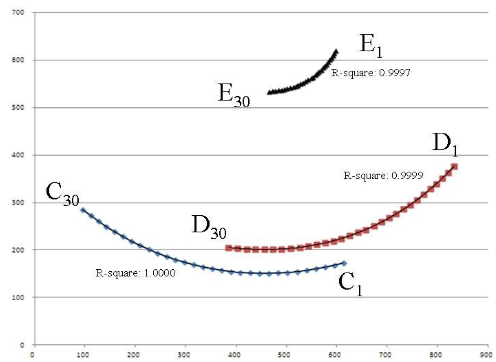


Figure 8. Curve fitting by exponential function

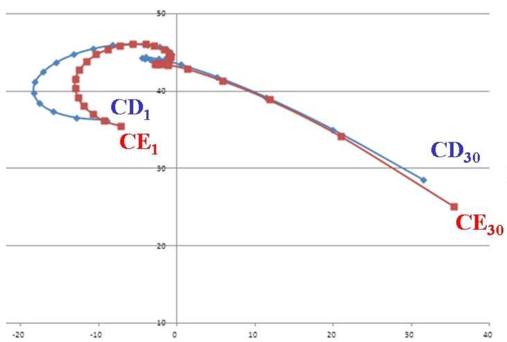


Figure 9. Centrodes using polynomial function

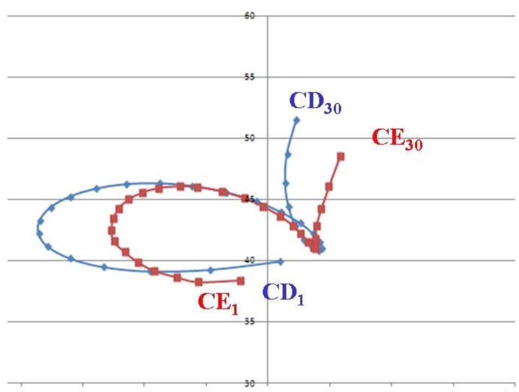


Figure 10. Centrodes using exponential function

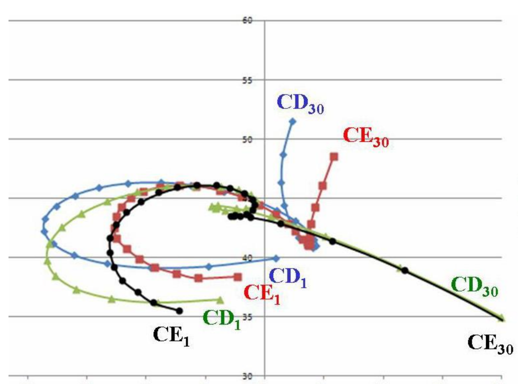


Figure 11. Comparison of centrodes

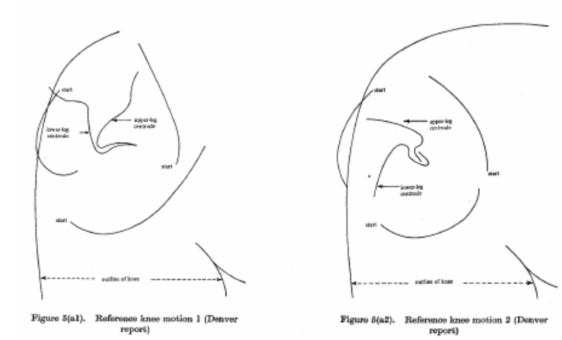
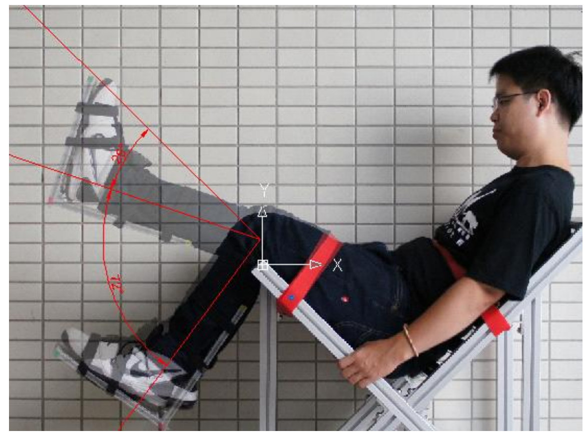
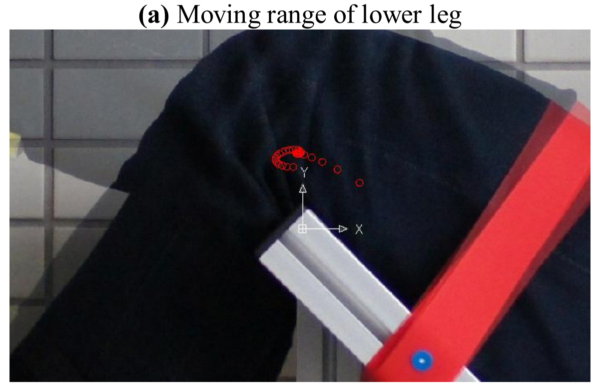


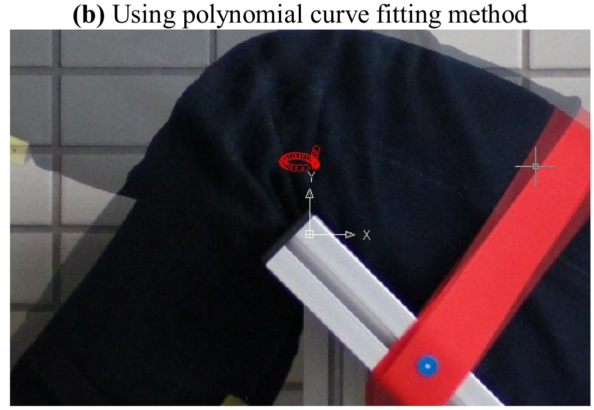
Fig. 12 Centrodes of knee joint from the X-ray data [2]



(a) Moving range of lower leg



(b) Using polynomial curve fitting method



(c) Using exponential curve fitting method

Figure 13. Centrodes of knee joint

5 Conclusion

Although the sequential X-ray radiographs of the moving knee provide an ideal data base for constructing the centrodes of knee joint, the cost and side effects of radiation may bothersome. This paper provides an alternative method to construct the centrodes by using commercial digital camera to take the sequential digital photographs. In order to eliminate the undesired movements, a testing chair and a brace are specially designed. Two types of curve fitting methods are introduced to smooth the measured data of three marked points on the lower leg. Since it is very sensitive to the accuracy of the measured data, the finitely separated position method is not an ideal one for determining the centrodes of knee joints. Therefore the differential method is applied to construct the centrodes of knee joint from the measured data. Although the accuracy of centrodes obtained in this study is around 5mm due to the errors of measured data, this paper still provides a non-expensive, non-invasion, and non-radiation way for people to study the centrodes of human knee joint.

Acknowledgements

The authors would like to thank the National Science Council, Taiwan, R.O.C., for financial support under grant No: NSC 99-2632-E-230-001-MY3.

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References

1. Nwoye, C.I., Obasi G.C., Nwoye U.C, Okeke K., Nwakwuo C.C. and Onyemaobi O.O., "Model for calculating the concentration of upgraded iron designated for production of stainless steel based biomedical devices used in Orthopaedics, " Life Science Journal, Vol. 7, Issue 4, 2010, pp. 1-6.
2. F. Freudenstein, L. S. Woo, "Kinematics of the Human Knee Joint," Bulletin of Mathematical Biophysics, Vol. 31,1969.
3. Frankel, V.H., Burstein, A.H., Brooks, D.B., "Biomechanics of internal derangement of the knee: pathomechanics as determined by analysis of the instant centers of motion," The Journal of Bone and Joint Surgery, 1971, 53: 945-977.
4. Hobson, D.A. and Torfason, L.E., "Optimization of four-bar knee mechanisms-A computerized approach," Journal of Biomechanics, Volume 7, Issue 4, 1974, pp. 371-376.
5. Menschik, A., "Prosthetic knee joint for attachment to a natural or prosthetic leg," US Patent 3969773, 1976.
6. Van de Vee, P. G., "Swivel connection between two parts of an orthopedic technical aid," US Patent5181931, 1993.
7. Hollman, J. Hl, Deusinger, R.H., Van Dillen, L.R., Matava, M.J., "Knee Joint Movements in Subjects Without Knee Pathology and Subjects With Injured Anterior Cruciate Ligaments," Physical Therapy, Volume 82 . Number 10, 2002, pp. 960-972.
8. Lee, J. M. and Chang K. Y., "An integrated investigation of CAD/CAM for the development of custom-made femoral stem, " Life Science Journal, Vol 7, No 1, 2009, pp. 56-61
9. Lee J.N., Chen, H.S., Luo, C.W. and Chang K.Y., "Rapid prototyping and multi-axis NC machining for the femoral component of knee prosthesis, " Life Science Journal. Vol. 7, no. 1,2010; pp. 79–83.
10. Shereif, W.I. and Hassanin, A.A., "Comparison between uses of therapeutic exercise and heat application on relieve pain, stiffness and improvement of physical function for patient with knee Osteoarthritis, " Life Science Journal, Vol. 8, No. 3, 2011, pp. 388-396.
11. Tien, Y.K. and Yu, C.K., "Tai chi exercise affects the isokinetic torque but not changes hamstrings: quadriceps ratios, " Life Science Journal, Vol. 6, No. 4, 2009, pp. 50-55.
12. Green, M.P., Radcliffe, C.W., "Technical report on the TGK-5PS0SLK, TGK-5PS0 and the TGK-50S0 PC Knee Units," DAW Industries Inc. technical report, 2003.
13. Muggleton, J. M., Allen, R., "Insights into the measurement of vertebral translation in the sagittal plane,"Medical Engineering & Physics, 20, 1998, 21–32.
14. Rousseau, M., Bradford, D.S., Bertagnoli, R., Hu, S.S., Lotz, J.C., "Disc arthroplasty design influences intervertebral kinematics and facet forces," The Spine Journal 6, 2006, 258–266.
15. Stark, G., "Overview of Knee Disarticulation," Journal of Prosthetics and Orthotics, Vol. 16, Number 4, 2004, pp. 130-137.
16. Vujić, D., Radojković, S., "Synthesis procedure of planar bar linkages in infinitesimally close position," FACTA UNIVERSITATIS Series: Mechanical Engineering, Vol.1, No 7, 2000, pp. 835–848.
17. Wu, T.-M., Chen, C.-K., "Computer-aided curvature analyses of planar four-bar linkage mechanism," Applied Mathematics and Computation 168, 2005, 1175–1188.
18. Hall, A.S., Kinematics and Linkage Design, Waveland Press, 1986.

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