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Research Article

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Modeling of kinematic parameters for a healthy patella by PLS method

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ABSTRACT

The related parameters of knee joint for Chinese people are incomplete, especially for the healthy knee. RSA combined with finite element is an effective way to get the kinematic parameters of knee joint. The kinematic parameters will help to build the relationship between response and predictor by PLS (partial least square) regression method. It will solve the problem of multi-response and multi-predictor

Key words: RSA; Normalization; Multi-variable; PLS; Regression method

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INTRODUCTION

There are some researches on knee joint in China. MJ Sun et al.[1]had already measured the geometric dimension of the knee joint. Y Wang et al.[2] had built a 3D model for the knee joint. But the parameters relative to the knee joint is still incomplete, especially for the Chinese people's knee joint parameters. Therefore, it is of virtual important to collect the relative parameters of average people's knee joint with an accurate and noninvasive method. In this paper, attention is concentrated on Roentgen Sterephotogrammetric Analysis(RSA)[3-6] combined with finite element method which is a new way on knee joint researches and can get the kinematic parameters for the bones of knee joint and the skin markers in three-dimensional directions, which would help to get the relationship between bones and skin markers.

Patella (which is also called kneecap) is defined as the research object with the method introduced above in this paper. Partial least square (PLS) method is applied to find the relationship between bones and skin markers and a regression model is built then. On this basis, the research method of the bones in knee joint can be simplified. The kinematic parameters can be collected by the skin markers and the situation of the bones in knee joint can be predicted by the regression models.

EXPERIMENTAL SECTION

1. Experimental procedures
A healthy patella was chosen to be a research object. Three infrared markers were mounted onto the skin of the patella which was shown in Fig 1. The knee joint was allowed to bend and stretch regularly. A RSA correction box was used to capture the continuous motion of the patella and the three markers while bending and stretching by thirty exposures per second. And the exposure time was 0.1ms each time.(Fig.2)

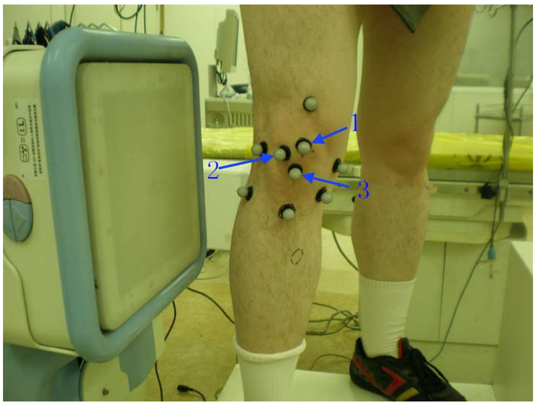

Fig.1 position of the three infrared markers

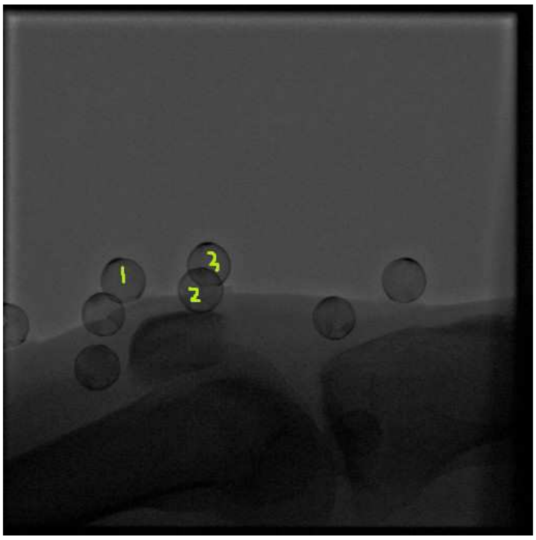

Fig.2 research object exposed by x ray.

The data for the experiment can be given as follows:

Table1 patella data (segment)

patella	X(y1)	Y(y2)	Z(y3)
1153	-38.3818	152.257	100.413

Table2 data for the three infrared markers(segment)

Number	Marker1			Marker2			Marker3		
	X(x1)	Y(x2)	Z(x3)	X(x4)	Y(x5)	Z(x6)	X(x7)	Y(x8)	Z(x9)
1153	-44.9317	-9.95395	236.177	-27.286	-3.6352	260.279	-19.4404	-0.0167	203.589

2. Computational methods and data analysis

When analyzing the relationship between the patella and the skin markers from motion capture data, one can deal with the problems by PLS method.[7][8]

(1) Construct the motion system.
(2) Standardize the motion parameters.
(3) Component analysis
(4) Regression modeling.

The PLS method was constructed in the above modeling framework.

2.1Construct the motion system

The motion of patella in X, Y and Z directions can be defined as response variables and can be denoted as y_1,

y_2 and y_3. The motion of skin markers in X,Y and Z directions can be defined as predictor variables and can be denoted as x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8 and x_9.

There would be nine predictor variables which would do harm to the regression model. So, the centre of gravity of spatial triangles had been found to simplify the predictor variables by the data in the experiment. And the new variables are x_{c1}, x_{c2} and x_{c3} which is illustrated in table3.

Table3 new variables (segment)

$data$	x_{c1}	x_{c2}	x_{c3}
1153	-30.5527	-4.53528	233.3483

2.2Standardize the motion parameters

The parameters with different units and magnitude should be standardized to eliminate the influence of dimension, which would make the parameter analysis more reasonable. The motion parameters were standardized by equation 1.

$$x_{ij}^* = \frac{x_{ij} - \bar{x}_j}{s_j}, \; i=1,2,\ldots,b; \; j=1,2,\ldots,p \quad (1)$$

The standardized motion parameters of the patella and skin markers were listed in table 4. The observation data matrix were $E_0 = [x_{c1}^*, x_{c2}^*, x_{c3}^*]$ and $F_0 = [y_1^*, y_2^*, y_3^*]$.

Table4 Standardized data (segment)

Standardize	x_{c1}^*	x_{c2}^*	x_{c3}^*	y_1^*	y_2^*	y_3^*
1153	0.553266	-2.10763	-0.48703	0.718711	-2.26337	-1.22067

2.3 Component analysis

According to the calculation, only two components should be extracted. The cross validation $Q_2^2 = -0.1045 < 0.0985$ which met the accuracy requirements of the model. The value of w_h and w_h^* were shown in table 6. The score $\hat{t}_h$ of the components t_h were listed in table 7.

Table6 value of w_h and w_h^* (segment)

variable	w_1	w_2	w_1^*	w_2^*
x_{c1}	-0.5215	-0.6324	-0.5215	-0.5323
x_{c2}	0.8208	-0.5552	0.8208	-0.7127
x_{c3}	-0.2331	-0.5402	-0.2331	-0.4954

Table7 score $\hat{t}_h$ of the components t_h (segment)

No	1	2	3	4	5	6	7	8	9	10
$\hat{t}_1$	-1.9049	-3.1034	-2.1147	-2.5295	-1.7710	-1.5028	-1.7900	-1.7071	-0.9420	-1.1496
$\hat{t}_2$	1.4489	-0.7839	0.6987	-0.2703	0.2022	-0.1085	-0.4657	-1.0328	-0.1124	-0.5850

2.4 Regression model

Regression model of $\tilde{y}_k$, t_1 and t_2 can be made according to table6 and table7.

$$\tilde{y}_k = r_{1k}t_1 + r_{2k}t_2, k = 1, 2, 3 \qquad (2)$$

A function can be created by the former standardized variable $\tilde{x}_j$ and component t_h.

$$t_h = w_{1h}^*\tilde{x}_1 + w_{2h}^*\tilde{x}_2 + w_{3h}^*\tilde{x}_3 \qquad (3)$$

The PLS regression model can be built by components t_1 and t_2.

$$\tilde{y}_k = (r_{1k}w_{11}^* + r_{2k}w_{12}^*)\tilde{x}_1 + (r_{1k}w_{21}^* + r_{2k}w_{22}^*)\tilde{x}_2 + (r_{1k}w_{31}^* + r_{2k}w_{32}^*)\tilde{x}_3 \qquad (4)$$

Where, r_h represents for regression coefficient. The model can be as follows by taking all the parameters in.

$$\tilde{y}_1 = -0.0783\tilde{x}_1 + 0.1395\tilde{x}_2 - 0.0323\tilde{x}_3$$
$$\tilde{y}_2 = -0.0372\tilde{x}_1 + 0.986\tilde{x}_2 + 0.1374\tilde{x}_3$$
$$\tilde{y}_3 = -0.2710\tilde{x}_1 + 0.6688\tilde{x}_2 - 0.0809\tilde{x}_3$$

To undo the standardized variables into original variables, the regression equation can be,

$$y_1 = -47.2689 - 0.2342x_1 + 0.0536x_2 - 0.0331x_3$$
$$y_2 = 58.1512 - 0.3115x_1 + 1.0603x_2 - 0.3940x_3$$
$$y_3 = 87.8745 - 1.4400x_1 + 0.4562x_2 - 0.1472x_3$$

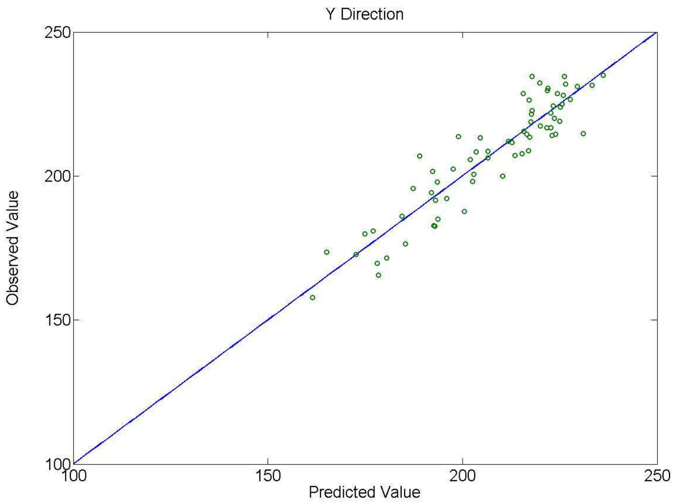

Fig.3 Predicted value in X direction

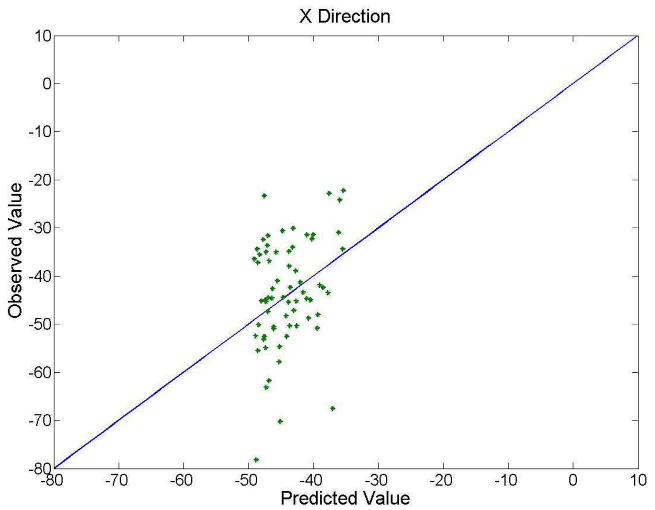

Fig.4 Predicted value in Y direction

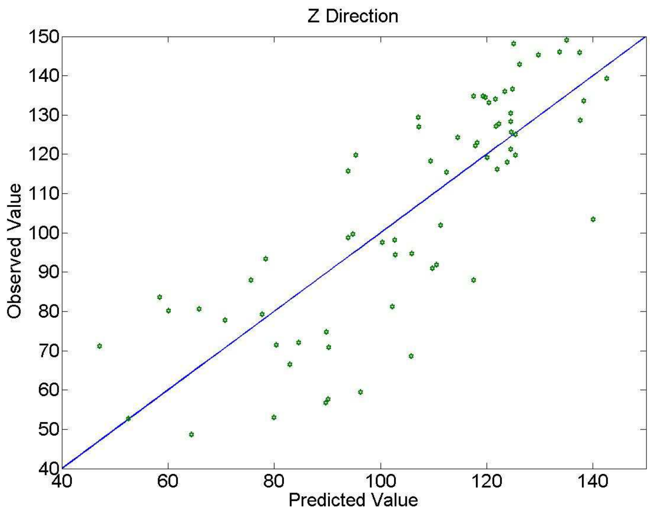

Fig.5 Predicted value in Z direction

RESULTS

In order to evaluate the accuracy of the regression equation model $(\hat{y}_{ik}, y_{ik})$ was taken as coordinate value to draw the prognostic map of all sample points. $\hat{y}_{ik}$ Was the kth variable, (y_{ik}) was the predicted value of the ith sample point and can be shown in Fig.1, Fig.2 and Fig.3.

As it was shown in Fig3, the asterisk was a two-dimensional point combined with the experimental value and the fitted value. It was clear that the asterisks were not equally distributed and the imitative effect of the equation was not satisfactory. The accuracy of the model should be improved.

As it was shown in Fig.4 and Fig.5, it was clear that the circles and stars were equally distributed and the imitative effect of the equation was satisfactory. The accuracy of the model was quite ideal.

CONCLUSION

PLS method was applied in this paper, and a relationship between the RSA motion parameters and finite parameters. It had solved the modeling problem of muti-response variables to multi-predictor variables. The structure of the data had been simplified and the multi-dimensional data can be observed in two-dimensional data. In this paper, satisfying regression equation and accurate model had been got. But, there were still some equation didn't get the satisfying regression model and we can try to use non-linear PLS to solve this problem in the near future

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