의공학회지 : 제16권, 제2호, 1995
J. of KOSOMBE : Vol. 16, No. 2

연 구 논 문
95-16-2-12

인체 동작 분석기의 개발

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=Abstract=

Development of a Human Motion Analyzer

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We propose some applications of image processing techniques to extract quantitative measurements by using a camera system developed in Korea university and Catholic Medical School. From now on the system will be called as KCMOTION. The purpose of this study is to provide basic kinematic and kinetic data for the analysis of human movements and to find the clinical usefulness and reliability of the proposed motion analysis system. Two tests, sit-to-stand (STS) movements and pendulum test, are conducted by the system. The aims of the tests are to identify variability and reliability of KCMOTION to give some quantitative comparisons to the other systems. The result of STS movement are compared to the LOCUS ⅢD motion analyzer by the ratio of maximum flexion movement per body weight to the actual maximum flexion extension torque per body weight. That result in 29% and 33% for hip and knee joint, respectively in KCMOTION and 27% and 30% in LOCUS ⅢD System. The results of the pendulum movements are compared to that of using Cybex and Electrogoniometer with relaxation index, amplitude ratio, swing number and swing time. The results of relaxation index and amplitude ratio of the KCMOTION are between those of the Cybex and Electrogoniometer. We also observed that the KCMOTION detect more natural movement, from the results of swing number and time.

Key words : Motion Analyzer, Pendulum test, Sit-to-stand test, Relaxation Index, Amplitude Ratio, Cybex, Electrogoniometer

INTRODUCTION

In the last decade there has been an increasing concern to the human locomotor function by some quantitative assessments rather than purely speculative and academic researches. The significance of a quantitative human motion analysis has attracted many clinicians and engineers. Recently some countries have developed motion analyzers or gait analyzers by using multiple camera. Those systems using a fixed number of cameras (4 to 6), but the KCMOTION which we are developing is very flexible to the number of cameras that means we may choose the number of cameras depend on the applications or hospital environments. This paper presents one camera system case in the

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† This paper was supported (in part) by NON DIRECTED RESEARCH FUND, Korea Research Foundation, 1993
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system as an example to identify the variability and reliability of the system by applying to STS test and pendulum test on subjects. We conducted the experiments following the method published by T. Kotake and et. el.[1] for STS movement test and T. R. Han and et. al.[3] for the pendulum test. The STS and pendulum tests are very fundamental motion in every day life and the researches of normal and abnormal movement patterns of STS motion and pendulum motion analysis are very important for the study of kinematic analysis. The objective of our researches is how to evaluate the system. In this paper to solve the problem we compared the results of some parameters of the KCMOTION system with some other commonly used systems for STS (LOCUS Ⅲ D motion analyzer) and pendulum motion analysis (Cybex and Electrogoniometer)[1~4].

Over All System Configuration

The KCMOTION system for kinematic analysis consists of three distinct phases-data collection, trajectory computation and representation of the results. For a single camera system, as a special usage of the KCMOTION system, the overall system configuration is shown as in Fig. 1.

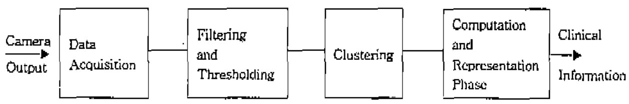


Figure 1. Overall configuration for KCMOTION one camera system

1. Data Collection Phase

For the first phase (data collection phase) we used a CCD camera and an image data acquisition board. The image data captured are smoothed out by a type of low pass filter. The filtered images are represented by binary images. We used a simple thresholding technique[5] such as

$$g(x,y)=\begin{cases}1 & \text{if } f(x,y)\geq T \\ 0 & otherwise\end{cases} \quad (1)$$

where f(x,y) denotes intensity values at a image on the horizontal position x and vertical position y and g(x,y) is the result image of thresholding process.

2. Trajectory Computation Phase

For the second, trajectory computation phase, clustering algorithm is applied to track the spatial trajectories of the markers which are attached on appropriate positions of the body. As an example, the binary image of Fig 2-(a) are represented only the potential marker positions by a vector.

$$P(i)=(x,y) \qquad \text{if } g(x,y)=1$$

where if g(x,y) equal to zero then disregard the position (x,y) because we may consider the position is outside of our concern. The binary image, as an example, of Fig. 2 (a) becomes a positional matrix as in Fig. 2 (b).

g(x,y)

	1	2	3	4	5	6	7	8
1	1	1	1	0	0	0	0	0
2	1	1	1	0	1	1	0	0
3	1	1	1	0	1	1	0	0
4	0	1	1	1	0	1	1	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0

(a)

→

p(i)

(1,1)
(1,2)
(1,3)
(2,1)
(2,2)
(2,3)
(2,5)
(2,6)
(3,1)
(3,2)
(3,3)
(3,5)
(3,6)
(4,2)
(4,3)
(4,4)
(4,6)
(4,7)

(b)

Figure 2. The positional vector for the positions of the whole markers

A clustering algorithm using a distance measure is applied to cluster each markers from the positional vector. Let i-th and (i+d)-th elements of the positional vector as P(i)=(n,m) and P(i+d)=(q,p), respectively. The maximum distance is defined by the size of the positional vector

P. We may define the distance measure as

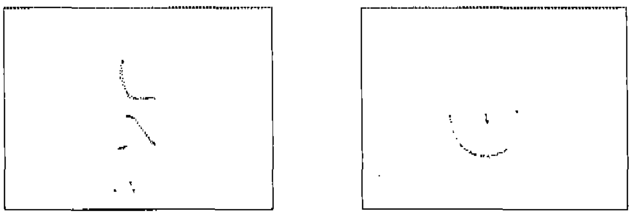
$$D(i) = \sqrt{(n-q)^2 + (m-p)^2} \quad (2)$$

The decision rule is defined if D (i) $\langle$= T then the positions that corresponding to the i-th and (i+d)-th positional vectors are same class otherwise the two positions are belong to different markers. The decision parameter T depends on the distance between subjects and camera. For the two test, STS and pendulum test, cases the subject and camera distances are relatively close enough, thus we define the parameter T as a square root of two that is the diagonal distance between two markers. To define the clustered marker as a one pixel size in image as in Fig 3, we calculated the center of the mass of the clustered marker as following

$$(x,y) = (int(\frac{1}{N_I}\sum_{x=I} x),\ int(\frac{1}{N_I}\sum_{y=I} y)) \quad (3)$$

where N_I is the number of pixels of the I-th cluster.

The results of the trajectory of positional information for STS and pendulum test are shown in Fig. 3 where each 80 and 250 frames of informations are used.

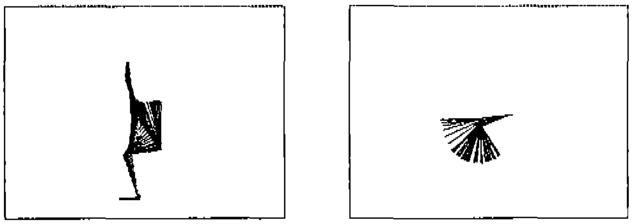


(a) (b)

Figure 3. Present the positional informations of 80 frames and 250 frames for STS and pendulum test, respectively.
(a) Markers position of STS test
(b) Markers position of pendulum test

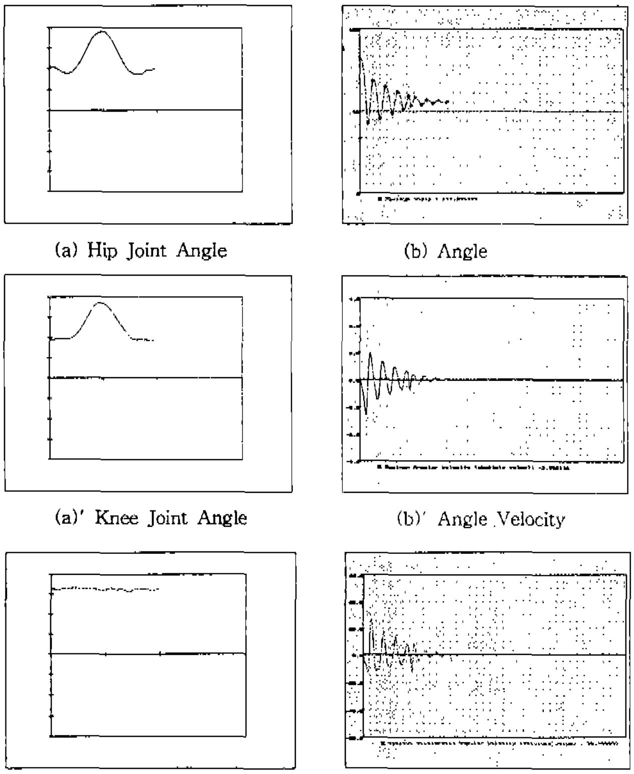
To find positional trajectories of the each markers a clustering algorithm[11] is used.

By identifying each markers in each frames the positional information can be converted to the trajectory of the positional information as shown in Fig. 4.



(a) (b)

Figure 4. The trajectories of the positional information for **(a)** STS test and **(b)** pendulum test



(a) Hip Joint Angle (b) Angle

(a)' Knee Joint Angle (b)' Angle Velocity

(a)'' Ankle Joint Angle (b)'' Angle Acceleration

Figure 5. **(a) (a)' (a)''** Hip, knee, ankle joint angle for STS test, **(b) (b)' (b)''** Angle, angle velocity and angular acceleration for Pendulum test

From the trajectory we compute the angle, angular velocity and angular acceleration for each markers as shown in Fig 5.

3. Representation Phase

Definitions for the computational models of the minimum unilateral hip joint and knee joint extension torque

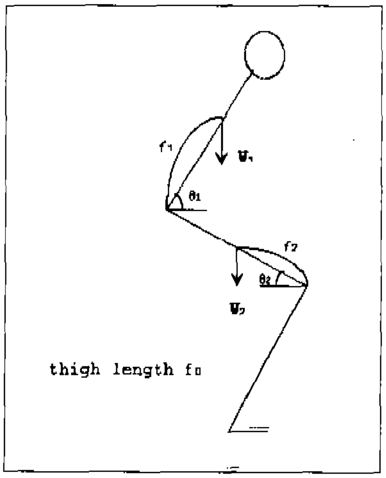


Figure 6. Computational model for STS movements

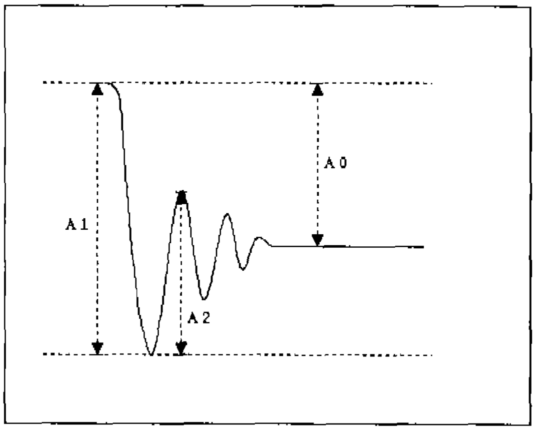


Figure 7. Parameters for pendulum tests (A0: Resting Angle, A1: Initial drop angle, A2: 2nd drop angle)

required to complete the STS movement is shown in Fig. 6.

The necessary hypothesis for the model in Figure 6 are established as in [1]. The torque for flexion of the hip joint and knee joint is calculated by (4) and (5), respectively.

$$H = w_1 f_1 \cos\theta_1 / 2 \quad (4)$$

$$K = w_1 [f_0 \cos\theta_2 - f_1 \cos\theta_1]/2 + w_2 f_2 \cos\theta_2 \quad (5)$$

where the parameters are defined in Table 1.

Table 1. Parameters for torque for flexion of the hip and knee joint

w_1	the torso weight including head and arms
w_2	thigh weight
θ_1	angle between the horizontal plane and the torso
θ_2	angle between the femur and the horizontal plane
f_0	distance from the center of gravity of the torso to the hip
f_1	femur length
f_2	knee joint distance from the center of gravity of the thigh

The maximum values of the torque for flexion of the knee joint and hip joint are denoted by Hmax and Kmax, respectively. The Hmax and Kmax represent the minimum unilateral joint extension torque required for completing the STS movement.

The computational parameters for the representation phase are listed in Table 2 and Figure 7.

Table 2. Parameters of Pendulum Test using KCMOTION

Relaxation Index (RI) = A1/A0
Amplitude Ratio (AR) = A1/(A1 − A2)
Number of Swing (cycle)
Swing Time (sec)

Table 3. Profiles of the subjects

Male (n=10)	Mean	Range
Age (years)	29.1	27~31
Weight (kg)	70.2	55~85
Height (cm)	173.5	165~180
Sitting Height (cm)	89.6	80~94
Thigh length (cm)	41.9	40~44

Subjects

We conducted the experiments for 10 healthy men with average age, average height, average weight, average height on the chair and the greater trochanter of the femur (thigh-bone) are defined 29.1 years old, 173.5 cm, 70.2 kg, 89.1 cm and 41.9 cm respectively, as listed in Table 3.

Table 4. Computational Maximum flexion Moment vs. Actual Maximum Extension Torque for KCMOTION system (A for KCMOTION and B for LOCUS Ⅲ D system)

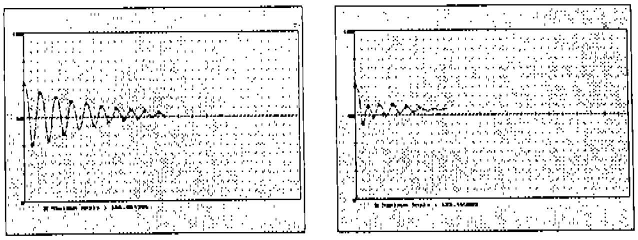
		Computational Maximum Flexion Moment(CMFM) per body weight(Nm/kg)	Actual Maximum Extension Torque (AMET) per body weight(Nm/kg)	CMFM/AMET (%)
A	Hip	0.81±0.12	2.79±0.15	29
	Knee	1.02±0.15	2.91±0.21	33
B	Hip	0.70±0.10	2.79±0.15	27
	Knee	0.90±0.10	2.91±0.21	30

Table 5. Normal Values of the Parameters

	Cybex	Electrogoniometer	KCMOTION
Relaxation Index	1.38	1.57	1.49
Amplitude Ratio	2.07	3.45	2.91
Swing No.	3.37	5.74	9.03
Swing Time	3.68	5.28	8.20

Table 6. Normal Values of the Parameters

	FLC	SP
Relaxation Index	2.09	1.55
Amplitude Ratio	5.98	1.90
Swing No.	13.75	6.2
Swing Time	14.67	5.79



(a) (b)

Figure 8. The knee joint angle change for abnormal cases **(a)** FLC **(b)** SP

Results and Conclusions

We conducted the experiment following the method published by T. Kotake and et. el. [1] for STS test. They used light-emitting diodes (LED) markers to some appropriate positions on the body of the subjects. Locus III D Motion Analyzer was used to record the movements of the markers. The results are expressed by the maximum values of the torque for flexion of the knee(Kmax) and hip(Hmax) joint per unit weight as follows,

$$Huw = Hmax / BWkg \quad (6)$$
$$Kuw = Kmax / BWkg \quad (7)$$

where BWkg is the body weight that measured by the unit of kilogram.

We calculated the average Huw and Kuw with standard deviation during natural sit-to-stand for 10 subjects listed in Table 3.

The results of the Locus III D Motion analyzer are reported the Huw and Kuw as 0.7 ± 0.1 Nm/kg and 0.9 ± 0.1 Nm/kg, respectively in[1]. Both systems figures represent theoretical values for the minimum hip joint and knee joint extension torque necessary for completing the sit-to-stand movement. The two system's results also represent that 29 % and 33% of the actual maximum extension torque for hip and knee using KCMOTION, and 27% and 30% using Locus III D system.

Another example that can be used 2-D motion analyzer is the pendulum test. The results of pendulum tests by the KCMOTION system are compared with the results of Cybex pendulum tests[2] and electrogoniometric pendulum tests. The parameters for comparisons are relaxation index, amplitude ratio, swing numbers and swing time as in Table 5. The results of the KCMOTION system indicate between Cybex and Electrogoniometer for relaxation index and amplitude ratio and longer swing time and more swing numbers are revealed by the KCMOTION system. This implies KCMOTION is a reliable device compare to the other two system(Cybex and Electrogoniometer). In KCMOTION, we can observed much greater swing number and longer time, because in our system does not impose any force on the knee in test process. The swing time result from the Electrogoniometer(5.28 sec) are approximately the time reach to the 70% of the maximum amplitude in KCMOTION. This means that the KCMOTION detect very natural movements.

Two abnormal cases (FLC and SP) are examined and the results of the change of angle with respect to time are shown in Fig. 8.

The corresponding values of the parameters of KCMOTION is listed in Table 6.

As we can see in Figure 8 or Table 6, FLC case the experimental results of relaxation index and amplitude ratio are very distinctive comparing with those of normal case, especially the amplitude ratio is very higher, but the SP case the relaxation index are reveal almost same as the case of normal but the amplitude ratio is comparatively higher than the normal case.

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