Multivariate Analysis of Joint Rotation in Okinawan Dance

Kiyoshi Hoshino

Faculty of Engineering, University of the Ryukus
and PRESTO, Japan Science and Technology Corporation
Nishihara, Okinawa, 903-0213 JAPAN
E-mail: hoshino@se.u-ryukyu.ac.jp

Abstract — To clarify the motion characteristics of free-style Okinawan dance "Kachaasi", first, the subjective impression was quantitatively evaluated with semantic differential technique to cluster its types. Then, the contingency of joint rotation in shoulder, elbow and wrist joints was examined with multivariate autoregressive model. The time-series data of positions and angles of three joints were calculated according to the deforming conditions and shielding directions of the ring lights. As the results, in an excellent dancer, the motions of shoulder and elbow were highly synchronized and smoothly controlled. The low-frequency output of the shoulder and elbow were mutually interacted. Meanwhile, the wrist behaved independently of other joints' rotation.

I. INTRODUCTION

Okinawan "Kachaasi" is a dance which is similar to "Awa-odori" dance of Shikoku Island of Japan. Kachaasi has no specific way of dancing nor regular sequence of operation. People enjoy the dance according to their feeling and emotion. Moreover, Kachaasi is two-beat and free-style dance, and it has various types of dancing, which signify that there is no decisive criterion for the skillfulness and excellence. However, it is possible to make clear evaluation even if an observer does not have any knowledge for the dance. It is very interesting in dancing to analyze the relation between psychological impression evoked and physical motion of arms and body.

Moreover, the Kachaasi dance is one of the interesting research topics from viewpoint of the cybernetics or computational theory in human brain. In an ordinary motion learning, the goal of control is definite and feedback information acquired by the control accomplished is clear. The motion is acquired to the direction which minimizes the control error. However, neither the definite control goal nor the clear feedback information seems to exist in Kachaasi which has a large number of degrees of freedom in the motion. In addition, there is a great number of degrees of freedom in the dynamics, because every motion in each single-degree-of-freedom system is realized by two kinds of muscles which antagonistically work. The mode of control for realizing a certain motion exists infinitely in the human musculoskeletal system. How can the skillful dance be created which impress many people? How does the brain carry out the computation to realize the sequence of motion in a dynamic system? This is another kind of big and interesting research topics to be investigated in the near future.

In the conventional motion analysis, only the time-series analysis of one variable has been carried out. This is because not only it is difficult to collect multivariate data which can stand the analysis but also practical analysis method itself has been lacking. But, many biological systems, including multiarticular motion of the human arm, are the multivariate feedback system. That is to say, a fluctuation of one variable is propagated in another variable, and output form the latter affects the former. It is impossible to quantify the relevance or contingency between variables by the time-series analysis only of each joint motion.

The present study adopts the multivariate autoregressive model [1] of three variables for the motion analysis of wrist, elbow and shoulder joints in Kachaasi dancing. In the model, white noise source is assumed which generates the characteristic vibration in each variable. By separating one's own output from output of some variables, we can quantify on how one oscillator controls each variable output. The relevance between the variable is described as power contribution when it was viewed in the frequency domain, and described as impulse response in the time domain.

In this study, therefore, semantic differential technique (SD method) was firstly adopted for subjective evaluation of Kachaasi. The method is frequently used in the multivariate analysis. The purpose of this first analysis is to clarify how many dimensions is included in Kachaasi to judge the skillfulness subjectively with. Secondly, the contingency and relevance of operation in shoulder, elbow and wrist joints' motion was investigated with the multivariate autoregressive model. The relation between the skillfulness of Kachaasi and the...
Fig. 1 Skillness scores in five dancers.

Fig. 2 Scores of subjective evaluation of Kachaasi in three-dimensional scales.

Fig. 3 Average scores in five dancers.
characteristics of motion was discussed on the basis of
the results obtained in first and second experiments.

II. SUBJECTIVE EVALUATION

As is mentioned in the previous chapter, people can
evaluate the excellence or skillfulness of "Kachaasi"
without any knowledge for the dance. No research has
been carried out which intends to quantify the subject-
ive evaluation for various ways of Kachaasi dancing.
The human subjective evaluation is positioned in three-
dimensional [2] or, at most, four-dimensional
rectangular coordinate space. However, previous studies
have been reported on neither the number of dimen-
sion for evaluation of the dance, nor types of evaluation
factor to estimate the skillfulness and poorness with.
In this chapter, therefore, SD method which is a gambit
of the multivariate analysis was adopted as a pre-
liminary experiment, and the extraction of evaluation
factor of Kachaasi was intended. In parallel, the fac-
tor which produces the impression of "being skillful"
is identified. SD method was adopted in this exper-
iment because it is easily possible with the method to
quantify the subjective image which people have.

First, the sample video was recorded for evaluation.
Five university students, both male and female, were
selected as dancers, whose skill of Kachaasi differed.
The five dancers were instructed to dance their own
Kachaasi to the accompaniment of the same music.
The dancers put on masks and inconspicuous clothes
to prevent the various kinds of impression caused by
other factor besides Kachaasi. Every dancing scene of
each dancer was recorded for thirty seconds.

Then, the questionnaire was prepared for SD
method. Our preliminary research has been carried
out beforehand, where pairs of estimation words were
freely reminded concerning the subjective evaluation
of Kachaasi. The results showed that Kachaasi has
three factors of "fineness vs. crudity" scale, "high
value vs. low value" scale, and "cheerfulness vs.
gloominess" scale. Therefore, each three frequently-
occur pairs of words in each factor plus "skillfulness
vs. poorness" pair were finally selected in the ques-
tionnaire. The total number of estimation word pairs
listed up for SD method was ten. Seven-stage evalua-
tion was adopted in this research.

Finally, the subjective evaluation of Kachaasi was
carried out with the questionnaire in thirty subjects
(male and female student, 19 through 37 year-old).
Each subject was instructed to observe the video of
five dancers for about one minute, and to estimate
the scores in each pair of words with sufficient time.
The subjects were required to report sex, birth place,
knowledge and experience of dance, and so on, besides
the Kachaasi's estimation.

Fig. 1, 2 and 3 are skillfulness scores with SD
method in five dancers, scores of subjective evaluation
in three scales, and average scores in five dancers re-
spectively. The results showed considerable dispersion
in the subjective estimation of Kachaasi which was
carried by not individual differences of subjects but
skillfulness of dancers. The scores dispersed within a
wide range in "fineness - crudity" and "cheerfulness
- gloominess" word pairs, which these two scales are
functioning in the estimation of Kachaasi. But the
scores were centralized in "high value - low value" word
pairs, which indicated that the value scale is not im-
portant for the estimation. The "skillfulness - poorn-
ness" scores was roughly in accordance with "cheerful-
ness - gloominess" scale, which suggests that people
estimate Kachaasi depending on how the dance seems
to be cheerful.

III. ANALYSIS OF JOINT MOTION

In the previous chapter, the subjective evaluation
of Kachaasi was carried out with SD method, and the
number of subjective dimension was examined in eval-
uation of Kachaasi. As the result showed, Kachaasi
itself was evaluated in mainly two factors: one is "fine-
ness - crudity" factor, and the other is "cheerfulness
- gloominess" factor. But in evaluation of the skill-
fulness of Kachaasi, only the cheerfulness-gloominess
factor is used. In this chapter, then, the multivariate
autoregressive model was adopted to analyzed the dif-
fences in dynamics of arm motion between skillfully-
estimated and poorly-estimated dances.

One video camera was used for the measurement,
because people usually observe and estimate Kachaasi
with the image represented from three-dimensional to
two-dimensional. Two kinds of light source were pre-
pared. One type was EL fiber of 3 mm diameter trans-
formed to the ring. Three EL lights were wound and
fixed to wrist, elbow and shoulder joints. The other
was a normal LED of 5 mm diameter, which was fixed
to a tip of the middle finger. The music used in this ex-
periment was comparatively slow. The subjects were
instructed to dance Kachaasi to the accompaniment of
the song.

The time-series data of three joint moments was cal-
culated after recording of video image data. First, the
centers of rotation of each joint was estimated accord-
ing to the shielding direction and deformation condi-
tion of the ring light-sources. Then, the joint an-
gular motions were obtained by the segments which
connected two joint centers adjoining. The sampling
frequency was 5 Hz. Two subjects served. One was
KMST (22-year-old, female student), who was esti-
mated as an excellent Kachaasi dancer by SD method.
The other was OSR (21-year-old, male student), who
was estimated as a good dancer. The Interrela-
ship or contingency of the three joint motion was an-
Fig. 4 Time-series changes of three joint rotations in an excellent dancer.

Fig. 5 Power spectra of joint rotations in an excellent dancer.

Fig. 6 Relative power contribution in joint rotations of an excellent dancer.

Fig. 7 Response of two joints to impulse input of one joint.
analyzed with the multivariate autoregressive model of three variables [1] in the frequency domain and time domain.

Fig. 4 and 5 are time-series changes of three joint rotations and power spectra of joint rotations in an excellent dancer respectively. The characteristics of time-series data of three joints were as follows: apparently, there was the periodic motion component in elbow and shoulder joints, the shifts were comparatively smooth, and these two motions were synchronized. But in the wrist joint, there were much noise and no synchronization was observed with other two motions, although there was the periodicity in the time-series change. Here, the score of angle is 90 degree when the wrist is stretched straight. The adduction increases the score to 180 degree. In the elbow joint, straight arm is defined as 180 degree. The angle approximately to 0 degree as it is bent inside. In the shoulder joint, the score of angle is 0 degree when the arm is perpendicularly lowered. The lifting of arm increases the score of angle to 180 degree.

The results of frequency analyses of three joints moments which were individually carried out were as follows: The autoregression coefficient was obtained by Burg method which can clearly show the spectral peak of power spectrum. The optimum degree was decide by AIC. The result showed that the optimum degree was approximately 16 through 18 order in every three joint. The results of power spectrum exhibited sharp peak, near at 0.3 Hz in all joints. This phenomenon was brought about by subjects’ repeating of the dance in the period of about three seconds. However, the harmonic frequency of 0.3 Hz exhibited other spectral peaks up to 1.2 Hz in shoulder and elbow. But the peak of the harmonic frequency was not remarkable in the wrist joint. These analyses signify that each power spectrum obtained by one-variate autoregressive model clarifies no contingency between three joints’ motion.

The contribution ratio of each residual in three variables, therefore, was analyzed to quantify the mutual control among three joints. Fig. 6 shows relative power contribution in joint rotations of an excellent dancer. In the power contribution ratio in wrist joint, most of the contribution ratio was occupied by itself in wide frequency bands. The results signifies that the wrist is not effected by movement of elbow and shoulder, and that it behaves independently. In the power contribution ratio in elbow joint, contrarily, elbow was greatly influenced by shoulder joint in the low frequency, although the high and middle frequency band components were produced by output from elbow itself. In the power contribution ratio of shoulder, output were defined by itself over whole frequency bands. But some parts of the low-frequency-component were synchronized with the behavior of elbow and wrist.

The autoregression coefficient is the coefficient which decides output for input of some variables. Therefore, the theoretical impulse response is defined by giving the train of impulse to a system. Fig. 7 shows response of two joints to impulse input of one joint. In the theoretical impulse response, there may be an area where responses advance to the negative region, which means that the effect of control works in the negative direction. The results were as follows: The impulse input to wrist and elbow gave no large effect for the response of other two joints. But the impulse input to the shoulder gave large effect in elbow and wrist joints. Especially, the initial stage of input tended to give the negative effect for elbow joint, which signifies that the elbow is once bent outside with some time delay when the arm is raised above, and that it is once bent inside when the arm moves down. Contrarily, the delay was big in the main response of wrist for the impulse input to the shoulder, compared with that in elbow. Moreover, the direction of response moved along the positive and negative, which signifies that the wrist complicatedly behaves.

The time-series waveforms of three joints were not very smooth in both excellent and good dancers. Moreover, the behavior of shoulder and elbow was not synchronized, and the wrist behaved considerably at random. The behavior of wrist showed the power spectrum which resembled 1/f noise in the result of frequency analysis in an individual joint. In the comparison of the power contribution ratio with the multivariate autoregressive model, the middle and high frequency band components were produced by its own output in shoulder and elbow, but the low frequency or vibrational component tended to produce output with mutual interaction. In comparison with two dancers, however, the contribution ratio of a joint for other joints was relatively low. Moreover, there were characteristic features in the response of elbow for shoulder among three joints. It moved in the negative and positive region, which suggests that the the elbow insufficiently cooperated with the shoulder.

IV. CONCLUSION

Okinawan traditional dance "Kachaasi" is similar to the famous "Awa-odori" dance in Shikoku, Japan. It is two-beat and free-style dancing, without any specific way of dancing or sequence of operations, and there are various types of dancing. There seems to be no decisive criterion for good or bad, however, it is practically possible to make a clear evaluation for it without any observers' knowledge for the dance. In the present study, the subjective impression of Kachaasi's skillfulness was quantitatively evaluated with semantic differential technique as a gambit of the multivariate
analysis. Then, the contingency of joint rotation in shoulder, elbow and wrist joints was examined during the dancing with multivariate autoregressive model.

The experimental procedures were as follows: only one set of video camera was used for measurement of the joint rotations. As the light sources, the ring-formed EL fibers were fixed around shoulder, elbow and wrist joints, and a LED was also fixed on the top of a middle finger. The time-series data of positions and angles of the joints were calculated according to the deforming conditions and shielding directions of the ring lights. The contingency or relevance of three joints was analyzed in the frequency and time domains using the multivariate autoregressive model.

The analysis was conducted to two subjects, an excellent dancer and a good dancer. In the high scorer, the motions of shoulder and elbow were highly synchronized and controlled smoothly. In the comparison of the power contribution ratio of multivariate autoregressive model, the shoulder and elbow produced their own output independently in the high or middle band frequency, however, the low-frequency output or vibrational components were mutually interacted. Meanwhile, the wrist behaved independently of other joints' rotation. These results suggested that the subjective impression of Kachaasi's skillfulness mainly depended on the synchronized fundamental frequency in the angular rotation of the shoulder and elbow.

References
