Ⅲ．研究成果の刊行に関する一覧表

別紙4

研究成果の刊行に関する一覧表レイアウト（参考）

書籍

著者氏名	論文タイトル名	書籍全体の編集者名	書　籍　名	出版社名	出版地	出版年	ページ
なし							

雑誌

発表者氏名	論文タイトル名	発表誌名	巻号	ページ	出版年
Shima Okada, Yuko Ohno	,New Approach for the Time Motion Analysis of Medical Staffs in a Ward by Video Image Processing	SICE, 2007 Proceedings	September	2750-2453	2007
Shima Okada, Yuko Ohno	New Approach for Medical Ward Monitoring Method by Difference Image Processing	International Conference on KEER 2007 Proceedings	October	CD-ROM	2007
Numasaki, H., Harauchi, H., Ohno, Y., Inamura, K., Kasahara, S., Monden, M., Sakon, M.	New classification of medical staff clinical services for optimal reconstruction of job workflow in a surgical ward: Application of spectrum analysis and sequence relational analysis	Computational Statistics & Data Analysis	51(12)	5708-5717	2007
手島 昭樹, 沼崎 穂高, 渋谷 均, 西尾 正道, 池田 恢, 伊東 久夫, 関口 建次, 上紺屋 憲彦, 小泉 雅彦, 多湖 正夫, 永田 靖, 正木 英一, 西村 哲夫, 山田 章吾, JASTRO データベース委員会	全国放射線治療施設の2005年定期構造調査報告（第1報）	日本放射線腫瘍学会誌	19	181-192	2007
手島 昭樹, 沼崎 穂高, 渋谷 均, 西尾 正道, 池田 恢, 伊東 久夫, 関口 建次, 上紺屋 憲彦, 小泉 雅彦, 多湖 正夫, 永田 靖, 正木 英一, 西村 哲夫, 山田 章吾, JASTRO データベース委員会	全国放射線治療施設の2005年定期構造調査報告（第2報）	日本放射線腫瘍学会誌	19	193-205	2007

Teshima, T., Numasaki, H., Shibuya, H., Nishio, M., Ikeda, I., Ito, H., Sekiguchi, K., Kamikonya, N., Koizumi, M., Tago, M., Nagata, Y., Masaki, H., Nishimura, T., Yamada, S., Japanese Society of Therapeutic Radiology and Oncology Database Committee	Japanese structure survey of radiation oncology in 2005 based on institutional stratification of patterns of care study	International Journal of Radiation Oncology Biology Physics	in press		
Uno, T., Sumi, M., Ishihara, Y., Numasaki, H., Mitsumori, M., Teshima, T., Japanese PCS Working Subgroup of Lung Cancer	Changes in patterns of care for limited-stage small-cell lung cancer: Results of the 99-01 patterns of care study - A nationwide survey in Japan	International Journal of Radiation Oncology Biology Physics	in press		
Aki Nakamura, Yuko Ohno, Yosuke Ooe and Takashi Nakamura	AThree-Year-Follow-up study on the Change in Physical and Mental Functions of the Aged by the level of ADL	Japan Hospitals	26	41-52	2007
越野八重美、大野ゆう子	Evaluation Parameters for Care-Giving Motions	Physical Therapy Science	19(4)	299-306	2007

Ⅳ．研究成果の刊行物・別刷

SICE Annual Conference 2007
Sept. 17-20, 2007, Kagawa University, Japan

New Approach for the Time Motion Analysis of Medical Staffs in a Ward by Video Image Processing

Shima Okada[1] and Yuko Ohno [2]

[1] Osaka University Graduate School of Medicine, Division of Health Sciences , Osaka, Japan
(Tel : +81-6-6879-2526; E-mail: shima@sahs.med.osaka-u.ac.jp)
[2] Osaka University Graduate School of Medicine, Division of Health Sciences , Osaka, Japan
(Tel : +82-6-6879-2526; E-mail: ohno@sahs.med.osaka-u.ac.jp)

Abstract: Time motion analysis is a popular tool for the job analysis of the medical staffs in a ward, especially for nurses. The usual time motion analysis is thought to be expensive and exhaustive for the study being conducted by trained observers continuously. Recently the more simple method is proposed applying the RFID, however, the study cost is also expensive and remains the ambiguity for the job detail analysis. In this study, we proposed a new approach for the time motion analysis applying the video image processing technique with difference imaging. The method can estimate the busyness of the staffs that operate in the room. And this new system requires no particular or expensive video system and computer system. For the verification on this method, we conducted verification experiment in the laboratory room. As the first step, in this research, the verification experiment was conducted at the outside of clinical site. And found its availability relating to the job analysis.

Keywords: Time motion analysis, difference imaging

1. INTRODUCTION

From the viewpoint of patient's safety in the hospital, the job analysis on the medical staffs is necessary to find the various risks in the ward. Especially for nurses, the effect of overabundant task and responsibility is seriously discussed concerning with the physical and psychological load. In addition, there are the following problems about safety of the caring to the patient, too. The question whether medical staffs are busy or not, overloaded or not should be investigated from many points of view, both from the subjective and objective. However, the investigation whether the medical staffs busy or not is mainly based on the subjectivity. So, the definition of busy and the quantification of the evaluation standard for medical staffs are difficult. Now a day, the research on the job analysis on the medical staffs is divided roughly into the following three, investigation of the job analysis on the medical staffs, investigation of the patient's outcomes and investigation based on the time study of medical staffs [1].

The time motion study on the medical staffs is the popular quantitative evaluation method that would clarify how much time the subject spent on the task. It is widely used on a clinical investigation for the doctor and other co-medical [2-5]. The reliability is thought to be high, however, there are several problems as follows; the researchers spent on the investigation a lot of time, the load to a clinical ward and test subjects are large and it costs very high.

Recently the more simple method is proposed applying the RFID [6-9]. But the RFID tag system is so complicated and the cost of the study is also expensive, furthermore, it remains the ambiguity for the job detail analysis because of the absent or deficient observation of the medical staff's movements.

In this study, we proposed a new approach for the time motion analysis applying the video image processing technique with difference imaging [10]. It can estimate the amount of the job in simple and low-cost way. The method can estimate the busyness of the staffs that operate in the room. And this new system requires no particular or expensive video system and computer system.

We presumed the amount of movement at the medical ward in each ward. And the busy degree at the medical ward in each ward can be quantified by comparing that. In this research, we propose the method of estimating the amount of movement in medical ward by using the difference image processing.

And to verify this, we conducted the verification experiment. As the first step of this study, in this research, the verification experiment was conducted at the outside of clinical site. And the system is composed of the commercially available equipment and the propriety and the reliability for clinical use was investigated.

The experiment assumed the medical ward; we compared changes in the amount of movement on an off hour of an Osaka University Graduate School of Medicine Health Sciences laboratory (They were six members in the max) and a peak hour (three people in the max).

2. METHODS

First of all, we noticed the amount of the movement of the medical staffs in hospital room, such as a patient's room. The amount of the movement of medical staffs is thought to reflect the busyness of the scene. In the new system, we propose the method of estimating the amount of movement in a scene based on the videotaped movement by using the difference image processing.

PR0001/07/0000-2750 ¥400 © 2007 SICE

In order to verify the system availability, we video-taped the day-scene of the laboratory of the graduate school of medical science in Osaka University and analyzed to compare the difference of the amount of the movement of a off hour and peak hour.

2.1 Subjects and facilities

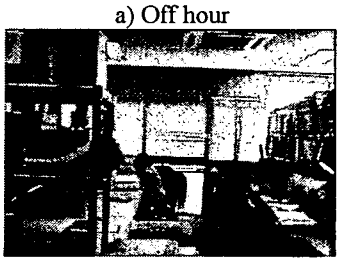
Members of Osaka University Graduate School of Medicine Health Sciences laboratory participated in the test as unpaid volunteers. A nod from subjects after fully explaining the purpose of the experiment, the procedure, and potential risk, ensured they understood completely.

As the first step of this study, in this research, the verification experiment was conducted at the outside of clinical site. The measurements were performed at Osaka University Graduate School of Medicine Health Sciences laboratory. The room was equipped with a video camera, and observers monitored the subjects' constantly at experiment day. A call buzzer was set up to call an observer in the event of an accident.

2.2 Experimental Procedure

We conducted the verification experiment. The experiment assumed the medical ward; we compared changes in the amount of movement on an off hour and peak hour in the Osaka University Graduate School of Medicine Health Sciences laboratory room. For the father video image analysis, we took video image in the laboratory room for three hours. The scenery were follow two condition, at an off hour and peak hour. Fig.1 shows the photographs of each experiment scene in the laboratory room.

a) Off hour



b) Peak hour

Fig.1 Photograph of experiment scenery in the laboratory room

2.1 Experimental System

This section explains the method for estimating the amount of movement by using difference image processing. We used a digital video camera recorder (DCR-PC120, made by Sony company, Japan) to record the scene. The video camera was fixed at the upper corner of the room by tripod stand to get the full dynamic image of the entire room. The video camera was connected with PC by using the IEEE1394 connection, and the dynamic image was stored directly on the hard disk of PC. Figure 2 shows the flow of the processing.

The dynamic image converted into the BMP still images. At this time, the frame rate is re-sampled from 10fps to 1fps. The size of the still picture is height 240[pixel]×width 340[pixel]. Next, the still images of the BMP form are continuously read and saved to the new file. Then, ROI (Region of Interest) is set for the speed-up of processing. Afterwards, the images are converted into the grayscale, and the change of the light and shade value between the frame at time t and the frame at time t+1 is detected. Using this value, the momentum of the subject is also estimated.

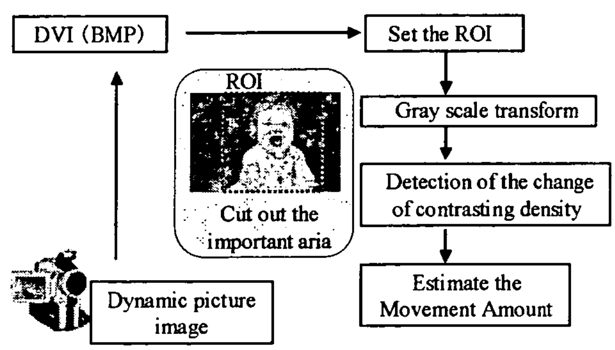


Fig.2 Summary of image processing

2.2 Detection of the change of contrasting density

The density value of the each pixel changes along with the movement of the object. The differentiation of the each change of the value of the thickness at all pixels at the time t and $t+1$ is calculated and the change of the density value of each pixel is detected. The size of the still picture is composed n pixels in the direction of x, and m pixels in the direction of y. Thus, it is expressed by $n \times m$ pixels matrix in total. When the density value procession of the frame at time t [t] is assumed to be matrix D(t) (see the equation (1)), differentiation procession matrix $\dot{D}(t)$ (see the equation (2)) is expressed as follows:

$$D(t)=\begin{pmatrix} d_{11}(t) & \cdots & d_{1n}(t) \\ \vdots & \ddots & \vdots \\ d_{m1}(t) & \cdots & d_{mn}(t) \end{pmatrix} \quad (1)$$

$$\dot{D}(t)=\begin{pmatrix} \dot{d}_{11}(t) & \cdots & \dot{d}_{1n}(t) \\ \vdots & \ddots & \vdots \\ \dot{d}_{m1}(t) & \cdots & \dot{d}_{mn}(t) \end{pmatrix} \quad (2)$$

The change of the density value at the one coordinates of the point (x,y) can be expressed by $\dot{d}_{xy}(t)$. According to the change of the density value in a certain pixel, the movement of the object is derived. The definition of the change of the density is as follows (ε in the conditional expression is a permissible error);

1) The case of density value increased:

$$|\dot{d}_{xy}(t)| > \varepsilon \qquad \dot{d}_{xy}(t) < 0$$

2) The case of density value decreased:

$$|\dot{d}_{xy}(t)| > \varepsilon \qquad \dot{d}_{xy}(t) > 0$$

3) The case of density value does not change:

$$|\dot{d}_{xy}(t)| \leq \varepsilon$$

We simulated the case where the black rectangle moves from time t [t] to time t+1[t] in a positive direction of x. Figure 3 shows the simulation result.

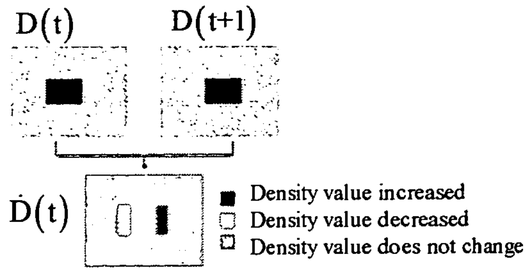


Fig.3 Result of simulation

2.3 Estimation of the amount of movement

When the object moves, the areas of increased density value would be spread. Therefore we estimated the amount of movement to count up the change of the number the pixels of increased density value. The number of density-increased pixels is divided by the number of all pixels on the screen is calculated.

3. RESULTS

We show the results of verification experiment. Fig.4 shows the results of head count at the laboratory room. The observer counted the number of people in the room by watching the video images. Fig.5 shows the results of estimated the amount of movement at the laboratory room.

a) Off hour b) Peak hour

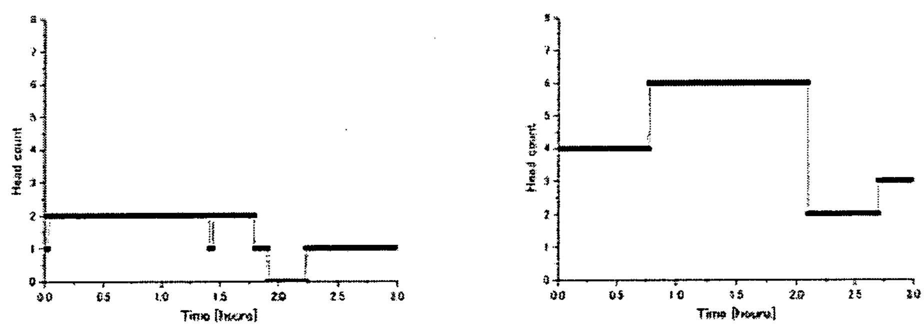


Fig.4 Results of head count

a) Off hour b) Peak hour

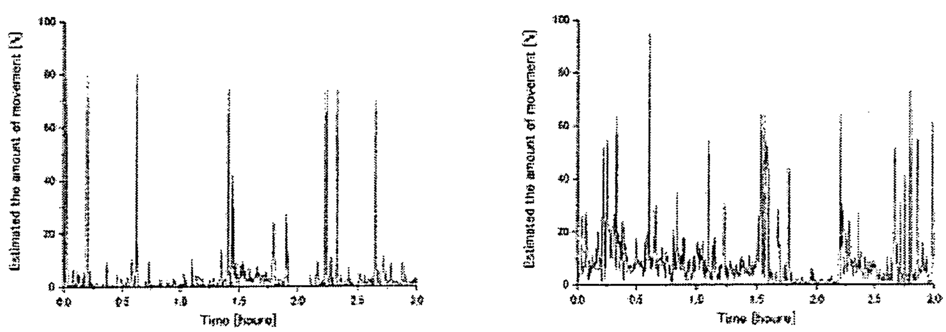


Fig.5 Results of estimated the amount of movement

In Fig.4 and Fig.5, the right hand of figure shows the result in the condition of off hour at the laboratory room and the left hand of figure shows the result in the condition of peak hour at the laboratory room.

As shown in Fig.4, there were up to two members in the laboratory room at the off hour and members went in and out the laboratory room. And we could confirm that there were up to six members in the laboratory room at the peak hour and members went in and out the laboratory room.

As shown in Fig.5, we could compare estimated the amount of movement between at the off hour and the peak hour. It can be confirmed that the base line of estimated the amount of movement at the off hour is almost about 10%. On the other hand, base line estimated the amount of movement is almost about 20% at the time of peak hour. To taken into consideration of the result of head count, it is thought that this is an appropriate result.

In addition, from both results, when the member went in and out from the room or operated greatly, the value of estimated the amount of movement to exceed 60% temporarily was seen.

4. CONCLUSION

The result of the verification experiment showed that the calculated amounts of the movement at an off hour exceeded those of peak hour in the laboratory. In this research, we demonstrated the new approach of the time motion analysis to estimate the amount of movement by using difference image. This system is seemed to be available and practical to investigate some special scene in the medical ward. In the future, we are planning the clinical time motion study in a clinical ward.

ACKNOWLEDGMENT

The authors would like to thank all participants of this study, for the significant contribution made to this study.

REFERENCES

[1] Meyers F. E. and Stewart J. R., "Motion and time study for lean manufacturing", Prentice Hall, 2002.

[2] Linda M. H., Diane D., George H. P., et al, "Nurse Staffing Models, Nursing Hours, and Patient Safety Outcomes", *JONA*, Vol. 34, No. 1, pp. 41-45,2004.

[3] S. P. Langlois, R. C. Vytialingam, N. A. Aziz, "A time-motion study of digital radiography at implementation", *Australasian Radiology*, Vol. 43, pp. 201-205,1999.

[4] Thomas A. B., Jerry R. M., Helen C. W., et al, "A Comparison of Time-and-Motion and Self Recording Methods of Work Measurement", *JONA*, Vol. 30, No. 3, pp. 118-125, 2000.

[5] Kayoko Inoue, Iwao Hirosawa, Miki Yatsuduka, " Utilization of a Voluntary Reporting System in Quantitative Risk Assesment for Medical Task in a Hospital Setting-with Special Reference to Tasks Done by Nurses", *Journal of Occupation Health*, Vol. 44, pp. 360-372, 2002.

[6] Chen CI, Liu CY, Li YC, Chao CC, Liu CT, Chen CF, Kuan CF, "The Application of RFID to Improve Patient Safety in Observation Unit of Hospital Emergency Department", *Study Health Technology Information*, Vol. 116, pp. 311-315, 2005.

[7] Krohn R. "RFID: it's about more than asset trac king", *J Health Information Management*, Vol. 1 9, No. 3, pp. 20-23, 2005.

[8] Perrin R.A., Simpson N., "RFID and bar codes--c ritical importance in enhancing safe patient car e", *J Health Information Management*, Vol.18, No. 4, pp. 33−39, 2004.

[9] Davis S., "RFID helps hospitals track assets and people", *Health Facilitation Management*, Vol.17, No. 12, pp. 20-24, 2004.

[10] Nakajima, K., "Evaluation of body motion by optical flow analysis", *Japanese Journal of Applied Physics*, Vol.36, pp.2929-2937, 1997.

New Approach for Medical Ward Monitoring Method by Difference Image Processing

Shima OKADA*, Yuko OHNO**

* *Osaka University Graduate School of Medicine, Division of Health Sciences, 1-7 Yamadaoka Suita-shi, Osaka, JAPAN, shima@sahs.med.osaka-u.ac.jp*

** *Osaka University Graduate School of Medicine, Division of Health Sciences, 1-7 Yamadaoka Suita-shi, Osaka, JAPAN, ohno@sahs.med.osaka-u.ac.jp*

Abstract: *From the viewpoint of patient's safety in the hospital, the method that monitoring of patient's movement in the bed has been needed. Recently the more simple method is proposed applying the pressure sensor mat. However, depending on patient's medical condition, there is a possibility that the accident might happen because of wiring in the vicinity of the bed and the bed with the sensor on an actual clinical site. Generally, it is known that "Feature extraction of body movement in the bed" shows an individual feature. The style of "Feature extraction of body movement in the bed" is different depending on the individual. It is difficult to evaluate "Feature extraction of body movement in the bed" quantitatively. So to evaluate "Feature extraction of body movement in the bed" quantitatively, we assume "Feature extraction of body movement in the bed" to be a kind of Kansei information and propose new approach for monitoring method by difference image processing. We propose the new method of the feature extraction of body movement by using dynamic image analysis. At first, we record a video of sleeping subject's state. The recorded dynamic image was taken into PC and it was converted into the still pictures of the BMP form for the following analysis. Next, we set the RIO area in the still pictures. And the finite difference analysis was continuously processed to the pictures. As a result, future of body movement was able to be detected in the time series.*

Key words: *Kansei information, Body movement, Difference image processing*

1. Introduction

It is said that he method that monitoring of patient's movement in the bed has been needed [1-2]. Generally, it is known that "Feature extraction of body movement in the bed" shows an individual feature. The style of "Feature extraction of body movement in the bed" is different depending on the individual [3-4]. It is difficult to evaluate "Feature extraction of body movement in the bed" quantitatively.

Now a day, some of methods have been previously proposed for extraction of body movement. Along with these, detection of the body movement by measuring changes in the electrical capacitance has also been reported [5]. And many new sensors that offer comparatively easy operation and installation have been developed. Such methods can measure not only body movement but also respiration and HRs from the internal pressure changes in an air mat [6]. However, these studies are only specialized in count of body movement. So they are not considered optimal way to detect the future of body movement in the bed.

So to evaluate "Feature extraction of body movement in the bed" quantitatively, we assume "Feature extraction of body movement in the bed" to be a kind of *Kansei* information and propose new approach for monitoring method by difference image processing.

In this paper, we propose the method of monitoring the patient's feature extraction of body movement in the bed applying the video image processing technique with difference imaging [7]. It can detect patient's feature extraction of body movement easily. And this method requires no particular or expensive video system and computer system.

For the verification on this method, we conducted verification experiments targeting male student, and found its availability relating to the subject's feature extraction of body movement.

2. Method

We noticed the Feature extraction of body movement in the bed. We propose the method of estimating the amount of movement in a scene based on the videotaped body movement by using the difference image processing.

2.1 Experimental System

We used a digital video camera recorder (DCR-PC120, made by Sony company, Japan) to record the subject's body movement. The video camera is fixed at the side of subject's head and gets the dynamic image of the entire subject's body. The video camera is connected with PC by using the IEEE1394 connection, and the dynamic image is stored directly on the hard disk of PC.

The dynamic image converted into the BMP still images. Next, the images are transformed the grayscale, and the change of the light and shade value.

2.2 Detection of the change of contrasting density

The density value of the each pixel changes along with the subject's body movement. The differentiation of the each change of the value of the thickness at all pixels at the time *t* and *t+1* is calculated and the change of the density value of each pixel is detected. The size of the still picture is composed n pixels in the direction of x, and m pixels in the direction of y. Thus, it is expressed by n×m pixels matrix in total.

The change of the density value at the one coordinates of the point (x,y) is expressed by $\dot{d}_{xy}(t)$. According to the change of the density value in a certain pixel, the movement of the object is derived. The definition of the change of the density is as follows (ε in the conditional expression is a permissible error);

1) The case of density value increased:

$$\left|\dot{d}_{xy}(t)\right| > \varepsilon \qquad \dot{d}_{xy}(t) < 0$$

2) The case of density value decreased:

$$\left|\dot{d}_{xy}(t)\right| > \varepsilon \qquad \dot{d}_{xy}(t) > 0$$

3) The case of density value does not change:

$$\left|\dot{d}_{xy}(t)\right| \leq \varepsilon$$

2.3 Detection of feature extraction of body movement

The mean value of the case of 1) and the case of 2) is calculated. We express the mean value of the case of 1) is (px,py) and the mean value of the case of 2) is (nx,ny). Next, we assume (px,py) to be center coordinates of the set of the pixel that the density value increases and (nx,ny) of the set of the pixel that the density value decreases. Center positional coordinates of the movement of the subject are expressed by calculating center coordinates of (px,py) and (nx,ny). Subject's center positional coordinates of the movement (x,y) are calculated according to the following equation;

$$x = \frac{px+nx}{2}$$

$$y = \frac{nx+ny}{2}$$

3. Results and Discussions

To verify our proposing method, we conducted the verification experiment. It was done targeting healthy man (height 172cm weight 73kg). He was on the bed and turned over in bed operation to the right side. The result of the movement of a still picture and center positional coordinates is shown in Figure 1. It can be confirmed that the subject turned over in bed and, the coordinate positions are calculated as well as the subject's movement.

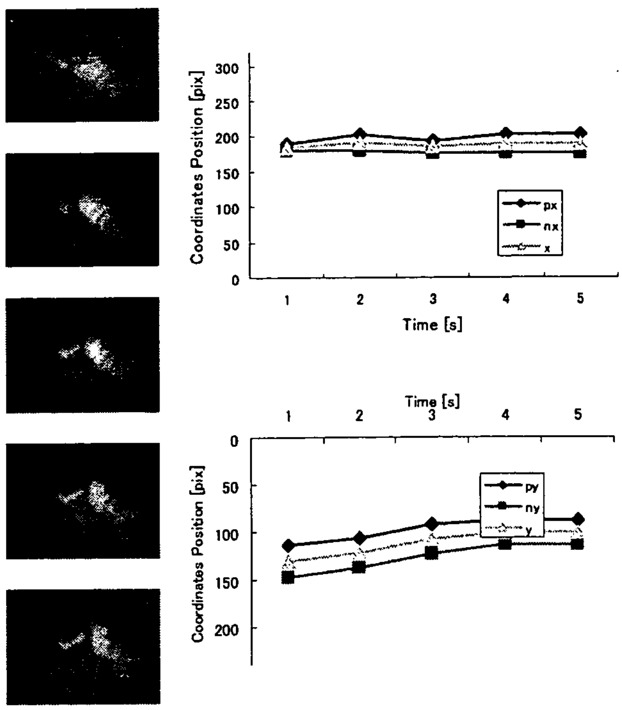


Fig.1 The result of the movement of a still picture and center positional coordinates

4. Conclusions

In this paper, we assume "Feature extraction of body movement in the bed" to be a kind of *Kansei* information and proposed new approach for monitoring method by difference image processing. As the result of the verification experiment, we confirmed that the method can be availableness.

The merit of this method is completely non-restrictive way. And we considered this way is effective for measurement of child's body movement. In the future, we apply this method for detection of child's feature extraction of body movement and try to verify the individual future as *Kansei* information.

5. References

1. Kayoko Inoue, Iwao Hirosawa, Miki Yatsuduka, "Utilization of a Voluntary Reporting System in Quantitative Risk Assesment for Medical Task in a Hospital Setting-with Special Reference to Tasks Done by Nurses", Journal of Occupation Health, 44, 360-372, (2002).
2. Chen CI, Liu CY, Li YC, Chao CC, Liu CT, Chen CF, Kuan CF, "The Application of RFID to Improve Patient Safety in Observation Unit of Hospital Emergency Department", Study Health Technology Information, 116, 311-315, (2005).
3. Kripke D. F., Mullaney D. J., Messin, S., Wyborney, V. G., Wrist actigraphic measures of sleep and rhythms, Electroencephalo Clin Neurophysiol, 11, 674-676, (1978).
4. Williams RL, Karacan I, Hursch CJ, Electroencephalography (EEG) of human sleep, Clinical Applications, John wiley & Sons, New York (1974).
5. Allihanka J, Vashtoranta K, Saarikivi I, A new method for long-term monitoring of the ballistocardiogram, heart rate, and respiration, Am J Physiol, 240, 384–392, (1988).
6. Watanabe H, Watanabe K, Non-invasive sensing of ballistocardiograms, respiration, snoring, body movement and coughing of a patient on the bed, Transactions of the Society of Instrument and Control Engineers(in Japanese with English abstract), 35-8, 1012–1019, (1999).
7. NAKAJIMA, K., Evaluation of body motion by optical flow analysis, Japanese Journal of Applied Physics, 36, 2929-2937, (1997).

Available online at www.sciencedirect.com

ScienceDirect

Computational Statistics & Data Analysis 51 (2007) 5708–5717

COMPUTATIONAL STATISTICS & DATA ANALYSIS

www.elsevier.com/locate/csda

New classification of medical staff clinical services for optimal reconstruction of job workflow in a surgical ward: Application of spectrum analysis and sequence relational analysis

Hodaka Numasaki[a,*], Hajime Harauchi[b], Yuko Ohno[c], Kiyonari Inamura[d], Satoko Kasahara[c], Morito Monden[e], Masato Sakon[f]

[a]*Department of Medical Physics and Engineering, Osaka University Graduate School of Medicine, Japan*
[b]*Department of Radiological Technology, Kawasaki College of Allied Health Professions, Japan*
[c]*Department of Health Promotion Science, Osaka University Graduate School of Medicine, Japan*
[d]*Department of Business Management, Kansai University of International Studies, Japan*
[e]*Department of Surgery and Clinical Oncology, Osaka University Graduate School of Medicine, Japan*
[f]*Nishinomiya Municipal Center Hospital, Japan*

Received 28 September 2004; received in revised form 31 May 2006; accepted 25 September 2006
Available online 19 October 2006

Abstract

In order to optimize the job workflow of medical staff, clinical job workflow was investigated from the viewpoint of its periodicity and the strength of causal association among jobs. Time-motion study for the staff at a surgical ward was carried out. To detect the periodicity of the occurrence of each job element, its frequency histogram was determined, and the discrete Fourier transformation was applied. For the analysis on the strength of the relationship among the job-sequence, the sequence relational analysis was developed, which was the expansion of the relation analysis to the sequence process. The job elements were classified into five incident patterns based on the periodicity of each element and into three patterns based on the association with other job elements. Based on time-motion study data, job workflow patterns of medical staff' were clarified based on the incident pattern of the job elements and the association with other job elements.
© 2006 Elsevier B.V. All rights reserved.

Keywords: Workflow; Time-motion study; Discrete Fourier transformation (DFT); Spectrum analysis; Root-mean-square (RMS); Relational analysis

1. Introduction

How to plan an efficient, effective, and safe hospital job workflow is a question of worldwide significance in hospital administration (Murray, 2002; Robert, 1998). Despite the number of reports discussing time-motion study in the medical field, as well as mathematical approaches, workflow continues to remain a major concern for hospital managers and medical staff (Harauchi et al., 1999; Hollingsworth et al., 1993; Ishii et al., 2002; Misener et al., 1987).

* Corresponding author. Tel./fax: +81 6 6879 2575.
E-mail address: numasaki@sahs.med.osaka-u.ac.jp (H. Numasaki).

0167-9473/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.csda.2006.09.029

In order to discuss the medical job workflow rationally, it is necessary to understand the actual job workflow quantitatively, modify the obtained information using computational analysis, measure each job element of the medical staff, and clarify the frequencies of actual medical job elements.

In this study, we propose a new classification of medical staff responsibilities, for optimal reconstruction of job workflow, using spectrum analysis and sequence relational analysis based on a series of time-motion data in a surgical ward in Japan. The classification has two viewpoints, the periodicity of job elements and the strength of interdependency among the job elements.

2. Materials

A time-motion study of the job workflow of medical staff (physicians, nurses, and nurse aides) was carried out from 1998 to 2001 in a surgical ward of a university hospital in Osaka, Japan. The time-motion study was performed for 24 consecutive hours. In order to maintain the accuracy of job element records, graduate students who were certified as nurses, radiological, and clinical laboratory technicians were assigned to record the medical staff job elements and their durations based on units per second (Finkler et al., 1993; Melissa and Betty, 1998; Thomas et al., 2000; Wirth et al., 1977). In the case of nurses, the ward used a primary nursing care system composed of three groups and three shifts per day (eight working hours per shift). All the members of the same group were observed for better understanding of the total number of job elements in the group.

Each observer recorded the job elements conducted by the nurse or physician in terms of "where," "since when," "until when," "by whom," "for whom," and "what job element," in a free format. No classified codes or templates were prepared before implementation of this study, in order to prevent prejudice and preconceptions of the observer. The recorded job workflow was checked in parallel with this study, in order to maintain accurate recordings.

During the total 23 study days of a four year study, all the job elements from a total of 188 staff members were recorded, and over 110,000 precise job element records were entered into the computer.

3. Methods

3.1. Classification of actual job elements by coding

The coding format for the observed data was defined by the Osaka Time-Motion Study Group, which consisted of academic researchers and experienced clinical staff members. Each category consisted of up to 175 items for nurses and 115 items for physicians. All the records of the job elements were uploaded on the time-motion database by trained specialists using a particular format.

3.2. Extraction of job element frequency using frequency analysis

Initially, each ward job element was investigated and categorized. Using all the data, identical job elements were grouped, and respective cumulative frequency histograms were plotted every 30 min, along with the time in days. Discrete Fourier transformation (DFT) was applied to the job element frequency data and a frequency analysis was performed. These steps were reiterated for each observed day and for each job element item.

3.3. Relational analysis of the job elements

The relationship between the job element sequences includes other aspects such as interdependency of some job elements. To measure this factor, we proposed a simple and effective procedure, referred to as root-mean-square (RMS), to determine the frequency difference between two different job elements at 10 min intervals throughout the day.

From the time-motion study database, the number of cases observed for every job element at 10 min intervals throughout the day was extracted. The RMS value of any two different job elements was calculated using the following expression:

$$RMS(\tau) = \sqrt{\frac{1}{T}\int_{-T/2}^{T/2} (f(t) - g(t+\tau))^2 \, dt}, \quad (1)$$

where, $f(t)$ is the function of the signal waveform for a certain job element, $g(t)$ the function of the signal waveform of another job element, and τ the phase difference (time difference) between the signal waveforms of $f(t)$ and $g(t)$. The correlations among the job elements were further investigated using these results.

4. Results

4.1. Classification of job elements by coding

Initially, the following two flags were prepared to discriminate simultaneously or ambiguously recorded job elements. (1) Serial job elements: this flag was used when an observer could not record the end of a job element because a medical staff member accomplishes many job elements quickly, in a short time. (2) Parallel job elements: these were applied when a medical staff member performed two or more job elements at the same unit time. For example, carrying out vital sign measurements such as thermometry along with observation of patient status and explaining the status to the patient.

The classification has three hierarchies for both physicians and nurses (Table 1). The hierarchies, from top to bottom, were "the purpose of the job element", "the category of the job element", and "the specified category of the job element."

Table 1 shows the number of classifications by year. While the first hierarchy shows the same number of categories, for the second and the third hierarchies, the numbers were different for each of the years. For physicians, the numbers of the third hierarchy varied from 105 to 115. In the case of nurses, the numbers were dispersed from 91 to 175. In Table 2, some examples of coding classifications for job elements are shown for the nurses in 1999.

Table 1
The number of classifications of each stage by code classification

Job description	Year	First hierarchy (Purpose)	Second hierarchy (Job classification)	Third hierarchy (Specified category)
Doctor	1998	4	33	115
	1999	4	29	105
	2000–2001	4	29	105
Nurse or nurse's aide	1998	4	30	175
	1999	4	33	169
	2000–2001	4	33	91

Table 2
Example of the code classification result of the job elements (Extract from the job elements of nurses in 1999.)

Purpose	Job classification	Specified category	Code No.
Nursing for recuperation	Comfort of a patient	Turning of own body	010901
		Applying a poultice	010902
		Massage	010903
		Preparation or cleaning up	0109J1
		Others	0109T1
Nursing for support medical practice	Exchanging information	Handing over	020701
		With a doctor	020702
		With other medical staff	020703
		Conference	020704
		Preparation or cleaning up	0207J1
		Others	0207T1
Other nursing	Moving or waiting	Moving	030701
		Waiting	030702
		Preparation or cleaning up	0307J1
		Others	0307T1

4.2. The occurrence periodicity of job elements

Based on DFT analysis, all the job elements were classified into five incident patterns by their occurrence periodicity.

(1) Occurring accidentally (emergent type): job elements that occur on an unscheduled or unpredictable timing basis, e.g., "call system."
(2) Occurring at all times (routine type): job elements that occur on a daily routine basis, e.g., "moving."
(3) Occurring regularly (time-dependent type): job elements that occur periodically at a scheduled time in a day, e.g., "conference."
(4) Occurring during spare time (arbitrary-provided type): job elements that are provided without time constraints, e.g., "self-learning."
(5) Exhibiting various occurrence patterns (mixed type): job elements that have mixed characteristics or show rather different occurrence tendencies among the observed days, e.g., "intravenous management."

Fig. 1 shows the occurrence frequency histogram of a routine type of job element for a nurse classified as "moving," while Fig. 2 shows the DFT results for the cited histogram. This job element occurred throughout the day (Fig. 1) and did not show periodicity (Fig. 2).

Fig. 3 shows the occurrence frequency histogram of a mixed type of job element for a nurse classified as "handing over," while Fig. 4 shows the DFT results for the cited histogram. This job element showed several periodicities (Fig. 4) and presented deviation in its incidence time (Fig. 3).

Fig. 5 shows the occurrence frequency histogram of a time-dependent job element for a nurse classified as "conference," while Fig. 6 shows the DFT results for the cited histogram. This job element occurred only at a scheduled time of day (Fig. 5) and did not show periodicity (Fig. 6).

4.3. Job element classification by the correlation

For the job elements classified as emergent type, routine type and time-dependent type, the RMS value was calculated, and the strength between the job elements was investigated. For example, the calculation result of the RMS value of

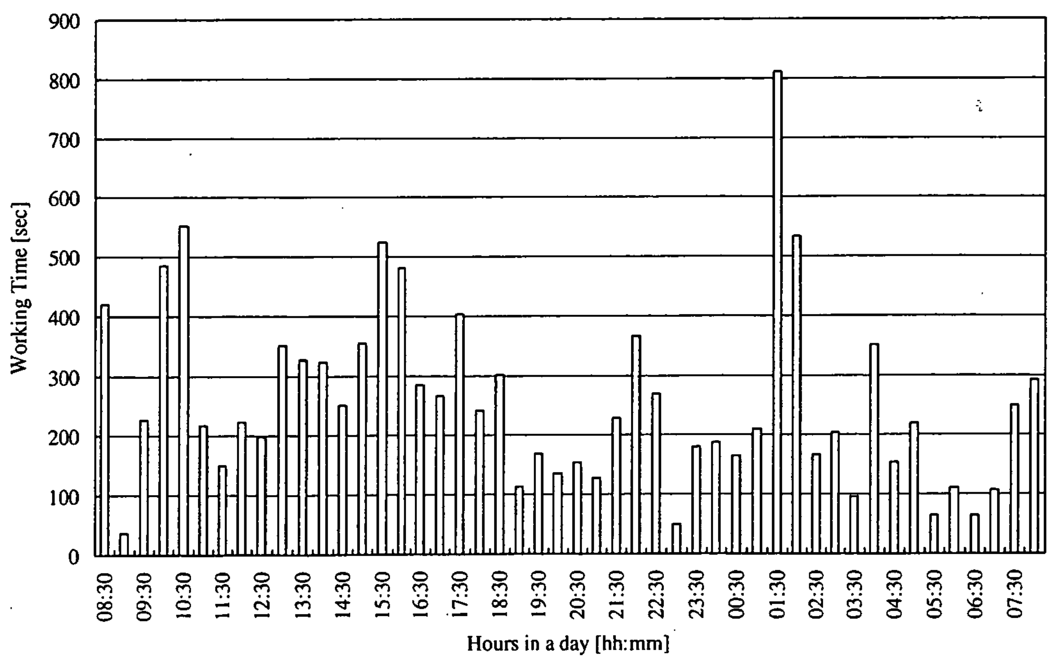


Fig. 1. Example of a histogram (Routine type job element of nurse: "moving".). The horizontal axis indicates hours in a day and the vertical axis indicates working time.

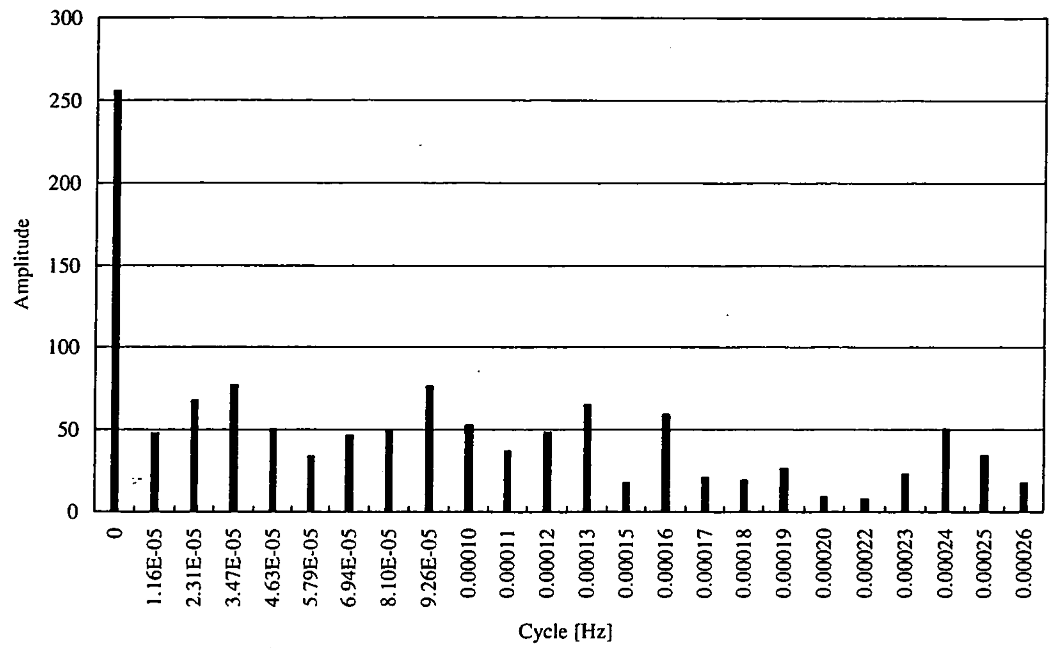


Fig. 2. Example of the result of DFT (Routine type job element of nurse: "moving".). The horizontal axis indicates frequency and the vertical axis indicates amplitude.

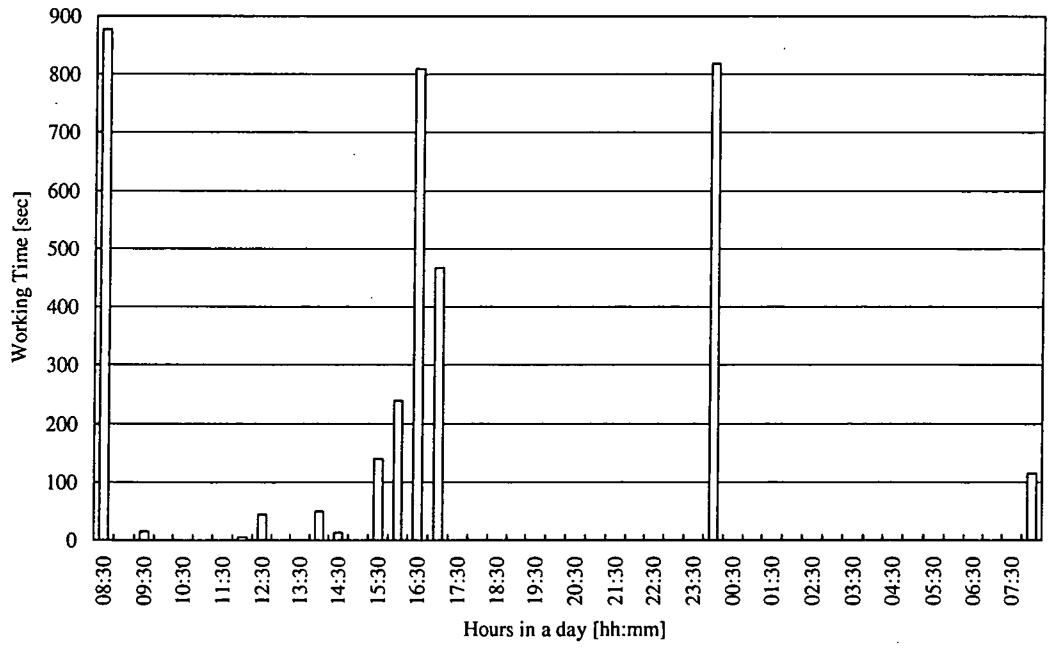


Fig. 3. Example of a histogram (Mixed type job element of nurse: "handing over".). The horizontal axis indicates hours in a day and the vertical axis indicates working time.

the difference in the number of cases between the job element of nurses classified as "bed-bath" and "preparation or cleaning up of bed-bath" is shown in Fig. 7. The ratio between these two job elements was 1:1 (The number of cases of "bed-bath" and "preparation or cleaning up of bed-bath" was 21 for both.). This graph shows one peak of RMS

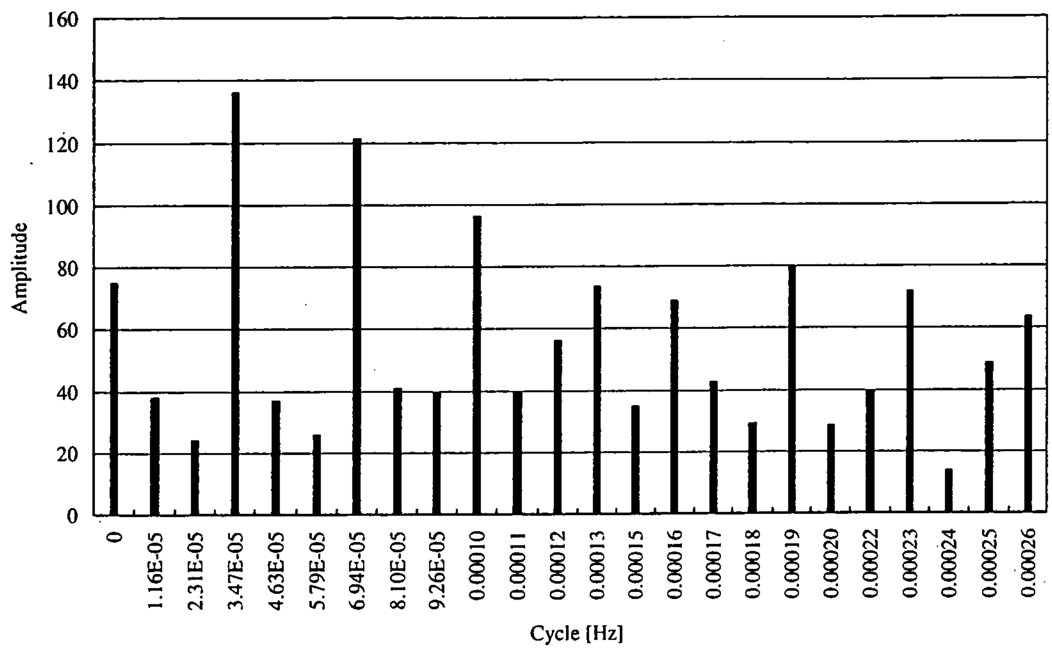


Fig. 4. Example of the result of DFT (Mixed type job element of nurse: "handing over".). The horizontal axis indicates frequency and the vertical axis indicates amplitude.

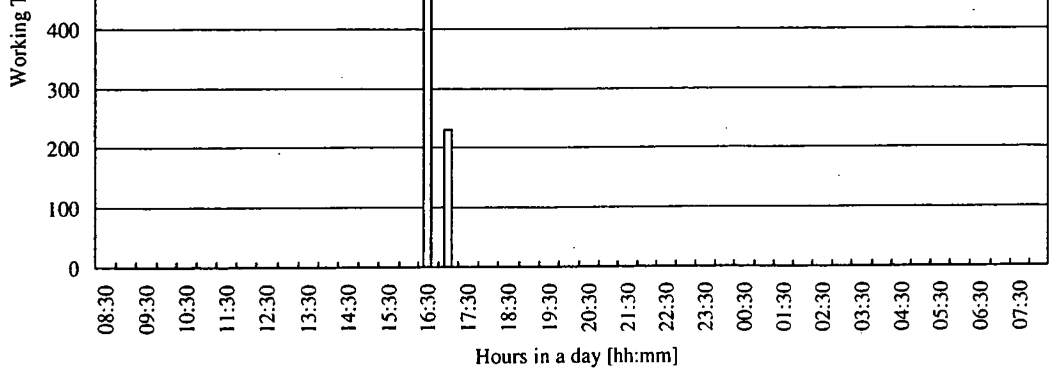


Fig. 5. Example of a histogram (Time-dependent type job element of nurse: "conference".). The horizontal axis indicates hours in a day and the vertical axis indicates working time.

value at a time difference of [+00 : 20] ([hh:mm],) which means that the job element of "preparation or cleaning up of bed-bath" was considered to occur about 20 min after the occurrence of the job element of "bed-bath."

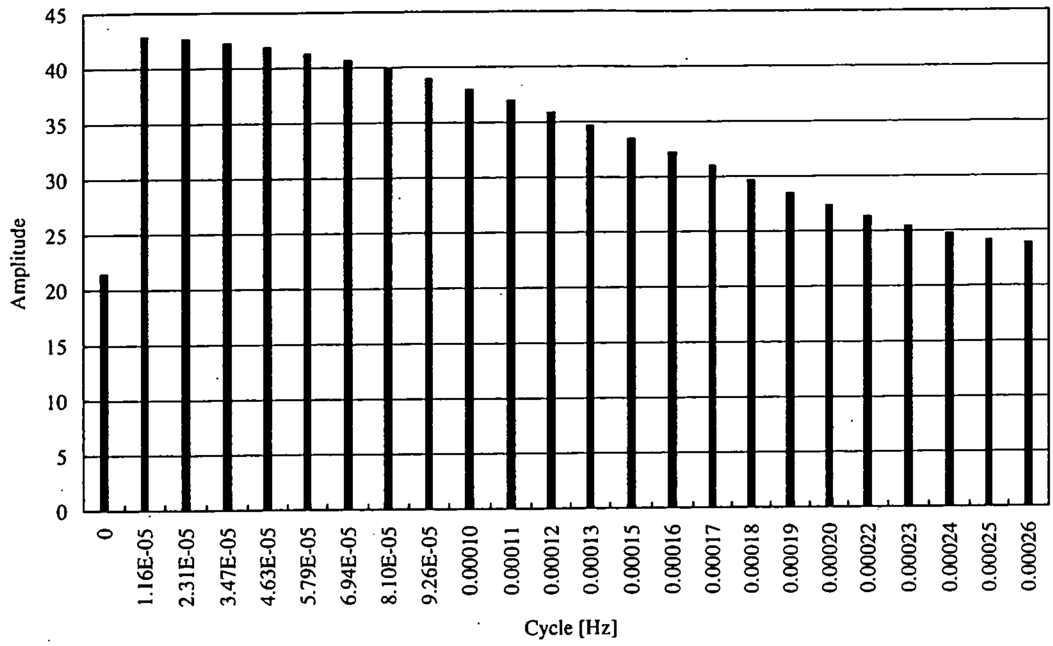


Fig. 6. Example of the result of DFT (Time-dependent type job element of nurse: "conference".). The horizontal axis indicates frequency and the vertical axis indicates amplitude.

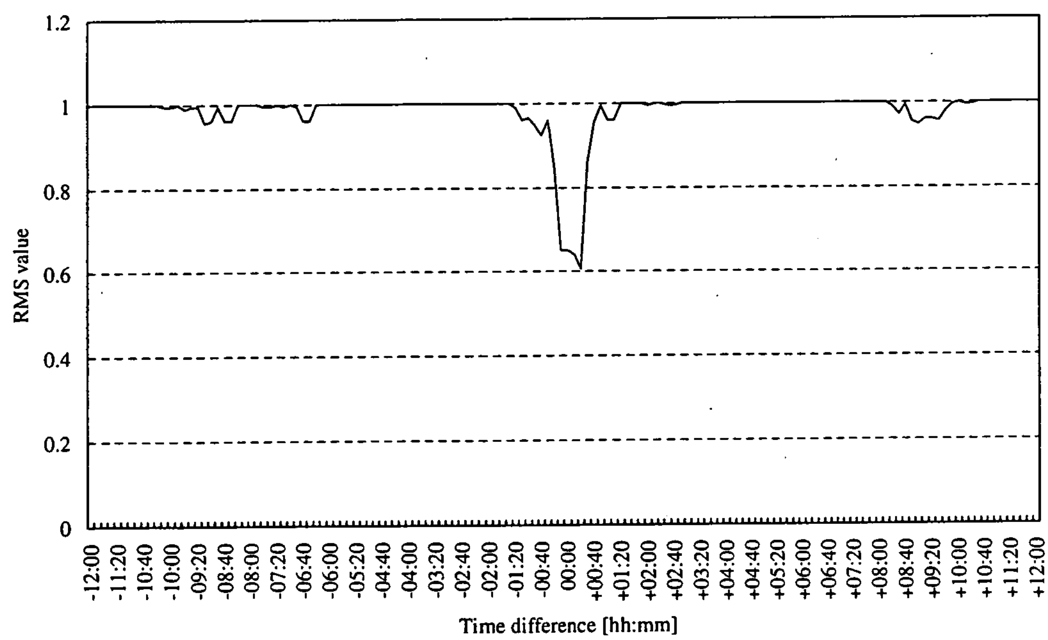


Fig. 7. Example of the calculation result of RMS value of the difference in number of cases between the job element of "bed-bath" and "preparation or clearing up of bed-bath". The horizontal axis indicates time difference and the vertical axis indicates RMS value.

The RMS value of the difference in the number of cases between the job element of nurses classified as "collecting information from a chart" and "handing over" is shown in Fig. 8. The ratio between these two job elements was 3:1 (The number of cases of "collecting information from a chart" and "handing over" was 107 and 36, respectively.).

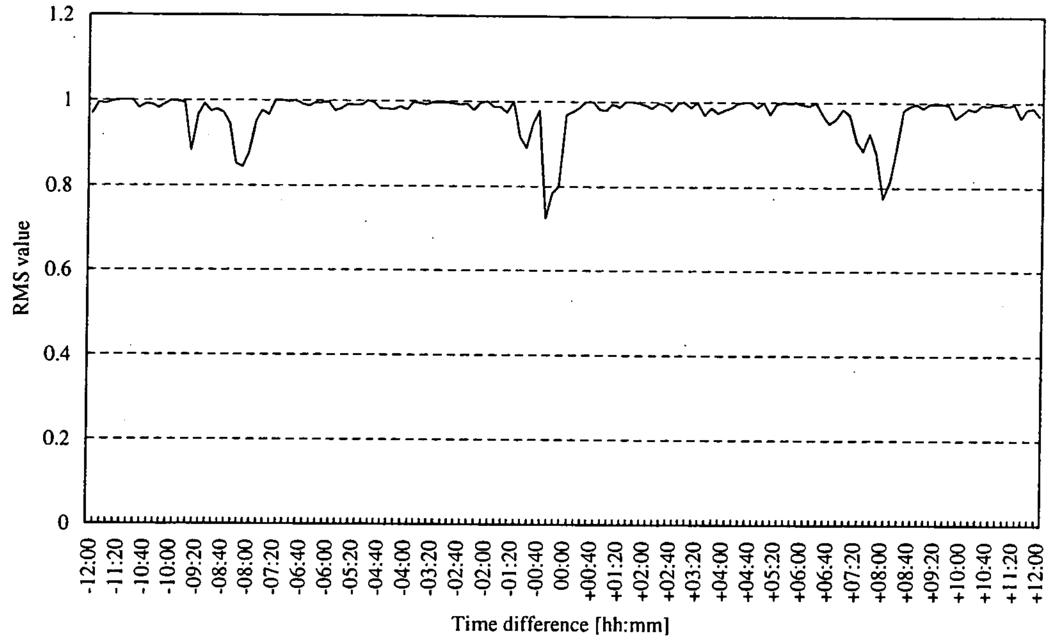


Fig. 8. Example of the calculation result of RMS value of the difference in number of cases between the job element of "collecting information from a chart" and "handing over". The horizontal axis indicates time difference and the vertical axis indicates RMS value.

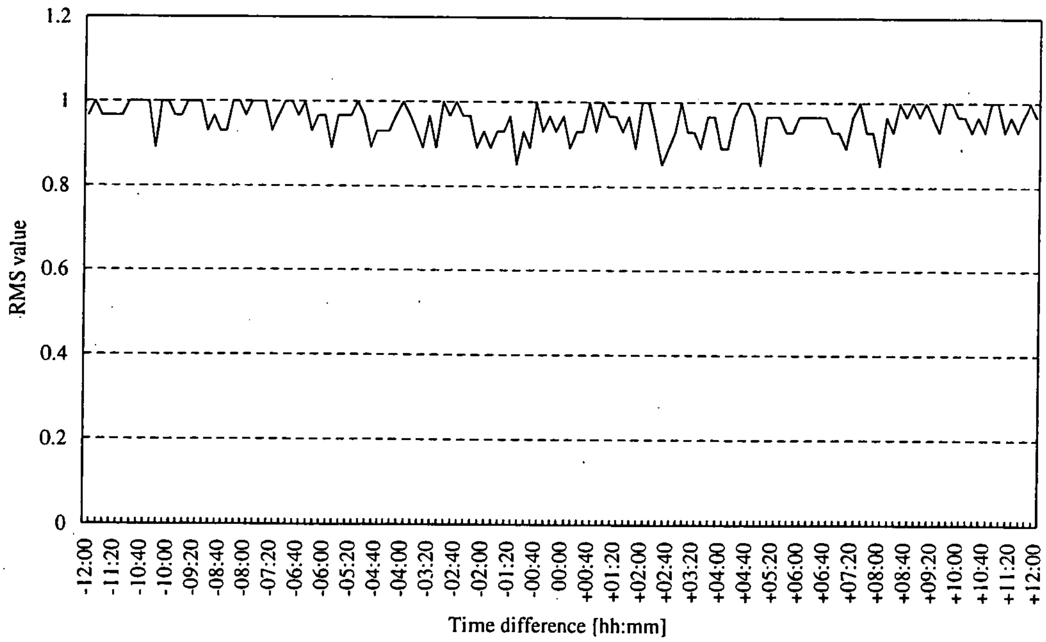


Fig. 9. Example of the calculation result of RMS value of the difference in number of cases between the job element of "answer patient–nurse call system" and "answer phones". The horizontal axis indicates time difference and the vertical axis indicates RMS value.

This graph demonstrates three peaks of RMS value with time differences of [−08 : 10], [−00 : 20], and [+07 : 50] ([hh:mm].)

The RMS value of the difference in the number of cases between the job element of nurses classified as "answer patient–nurse call system" and "answer phone" is shown in Fig. 9. The ratio between these two job elements was 1:1 (The number of cases of "answer patient–nurse call system" and "answer phone" was 13 and 14, respectively.). This graph demonstrates no peak of RMS value.

Table 3
Example of classification result by occurrence tendency for each job element (Classified job elements of nurse in 1999: 121 job elements in 169 job elements.)

	Independent type		Interdependent type	Random type
	Without time zone restrictions	With time zone restrictions		
Emergent type	24	6	10	9
Routine type	6	2	1	1
Time-dependent type	10		7	4
Arbitrary-provided type		9		
Mixed type		33		

From all the results, we found three types of relationships among the job element sequences.

(1) Independent type: job elements that did not show any relationship with any other job elements.
For the job elements classified as emergent type and routine type, we classified into additional two patterns by constraint of time in execution.
  1.1 Job elements with the constraint of time zone in execution
  1.2 Job elements without constraint of time zone in execution
(2) Interdependent type: job elements that had a conjunctive sequence with other job elements.
(3) Random type: job elements which were influenced the day of the week. Table 3 shows the integrated results of the job element classification of nurses in 1999.

5. Discussion

Many time-motion studies have been reported for job workflows concerning clinical medical staff in the United States, reports in this field, especially for physicians, are still quite rare in Japan. One of the reasons for this situation could be related to the passive attitude of some Japanese physicians toward hospital management.

The time-motion data used in this study was, for the first time, conducted at a surgical ward of a university hospital in Japan, and the database structure developed for this study is the most detailed and precise database currently in use. On the basis of this database a quantitative mathematical analysis was accomplished.

The advantage of this study is the new mathematical method proposed for the classification of the job elements, namely the periodicity and the strength of the relationships between the job elements. Until now, in the medical field, job elements based on classification by frequency have not been reported. By using frequency analysis, the job elements of the medical staff were clearly classified according to the distribution of their occurrence. Thus, as the relationship between the job elements was mathematically investigated, the strength of job element sequence was discussed quantitatively. In daily ward job elements, the periodicity can find influence on the job workflow and the feeling of busyness.

The results clarified the five types of job element (emergent type, routine type, time-dependent type, arbitrary-provided type and mixed type.) There is a chance that the proportion of each type would be different among wards, even in the same hospital. For example, the proportion of the emergent type job elements would be increased in an emergency ward, and the proportion of the arbitrary-provided type job would be increased in a chronic disease ward. The classification that we have proposed would be applicable to all the analyses of all clinical job elements.

Generally, the correlation between two job elements following the signal waveform $f(t)$ and $g(t)$ can be determined using a cross-correlation function. A cross-correlation function is obtained from the following formula:

$$R_{fg}(t) = \lim_{T\to 0} \frac{1}{T} \int_{-T/2}^{T/2} f(t)g(t+\tau)\,dt,$$

$$R_{fg}(t) = \frac{1}{N} \sum_{t=1}^{N} f(t)g(t+\Delta t). \tag{2}$$