Development of a System for Analyzing Working Postures

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Abstract: In order to assist in the analysis of working postures which might cause lumbago in the field of industrial health, a system was developed for the synchronous recording and analyzing of postures, work content and physiological data. The system is composed of a portable unit for recording 3 channels of goniometers, 1 channel of inclinometer and 1 channel of surface electromyogram, a video camera for recording work content, a host computer and some peripheral devices for analyzing the data from the portable unit and video camera. In this system, postures are automatically classified from data on joint angles and upper body inclination angle by using a discriminant function. The joint angles are measured by the goniometers using rubber optical fibers. The angle of upper body inclination is obtained by the inclinometer using a magnetic resistance sensor. In addition to the work content and video images, the postures and the electromyogram can be analyzed and confirmed by simultaneous display of the data on the host computer screen. Based on the trial use of this system in a work model of manual baggage handling, it was proved useful for evaluating in detail the workload caused by working postures.

Key Words: Workload—Posture—Goniometer—Inclinometer—Electromyogram—VTR

INTRODUCTION

Analyses of working postures are frequently carried out in the field of industrial health to evaluate workload due to posture\(^1-9\). The data used in analyzing posture are not limited to the posture (forward bending, half sitting, sitting, etc.). In most cases, data on work content (working processes, dealing with materials, etc.) and from physiological tests (heart rate, oxygen consumption, electromyogram, etc.) are also analyzed simultaneously.

The usual methods of analyzing working postures are direct observation or recording by video cameras for posture and work content, use of data recorders or telemeters for heart rate and electromyogram (EMG) for physiological load. Since these data are measured independently, the synchronous analysis of postures, work content and physiological data is very complicated.
We have developed an apparatus for analyzing posture\(^{10, 11}\), that measures the angles of joints and the angle of inclination of the upper body, and automatically classifies posture by using discriminant functions as the indices of lumbago. Observations of posture are not needed to follow workers with our apparatus. This paper reports further improvement of our apparatus, which achieved synchronous recording and analyses of work content and physiological data in addition to postures. Our new system can facilitate a comprehensive analysis of working postures.

**OUTLINE OF THE SYSTEM**

A block diagram of our system is shown in Fig. 1. The system is composed of a portable unit, video camera, host computer and other peripheral devices.

The portable unit is a standalone data recording unit, which can record three channels of joint angles, one channel of inclination angle and one channel of surface EMG. The unit measures 15 × 10 × 4 cm and weighs 500 g. It is enclosed in a cloth case and carried by the subject on a waist belt. The joint angles are measured by goniometers which use the bending loss of rubber optical fibers (ORNES, Bridgestone, Japan), as shown in Fig. 2 (length: 12 cm, weight: 10 g, measuring range: 0~140 deg, accuracy: 5 deg)\(^{10}\). The goniometers are fixed at the joints according to the various postures. The upper body inclination angle is measured by the inclinometer using a magnetic resistance sensor (LP06 M2F1AA, Murata, Japan), as shown in Fig. 3 (size: 5.5 × 4 × 2 cm, weight: 40 g, measuring range: −20~100 deg, accuracy: 5 deg, response time: 220 ms). The inclinometer is fixed at the front chest or upper back of the subject. The EMG is measured by bipolar surface electrodes (paste applied Ag/AgCl electrodes, Vitrode M−150, NIHON KOHDEN, Japan), and the signal of EMG is amplified, full-wave rectified and smoothed by a first-order lowpass filter (cutoff frequency: 0.96 Hz). All of the measured data are digitalized by an 8 bit A−D converter, and saved in the 30 KB memory, which is sufficient for 100 minutes of recording when three channels of joint angles, one channel of inclination angle and one channel of electromyogram are recorded every second. A one-chip CPU (8052, Intel, U.S.A.) is installed in the portable unit, and controls all of its functions. However it is necessary to connect the portable unit to the host computer (PC−9801VX2, NEC, Japan) for maintenance of the portable unit, such as setting up measuring channels and interval, calibrating goniometers and the inclinometer, etc. The measured data are analyzed by the host computer after being transferred from the portable unit to the host computer.

The video camera for recording and reviewing work content is an 8 mm type (TR−75, SONY, Japan). The video camera, which weighs 780 g, can record the working scene for up to 2 hours. When analyzing the video tape, the video camera is connected to the host computer by a control unit (Vbox CI−1000,
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Fig. 1. Block diagram of the system.

Fig. 2. Structure of goniometer. The light of the LED (light emitting diode) is conducted to a phototransistor through a rubber optical fiber. The LED and phototransistor are fixed on the segments of the joint. When the rubber optical fiber is flexed according to joint flexion, the light which reaches the phototransistor is reduced by the bending loss of the rubber optical fiber. The bending angle can be estimated from the output of the phototransistor.
SONY, Japan). This video camera has no function of recording absolute time data, but the data of the portable unit and video tape can be linked within one second of error without using external timing signals because of the precise internal timers of the portable unit and video camera and the frame control functions. The video image data are superimposed on the host computer screen by an image digitizing board (CVI-98II, Canopus, Japan) for simultaneous review of the data from video tape and portable unit.

The data analyses are carried out in the following steps. The first step is to create a data file of work content by reviewing the video tape. The video tape and the data file can be reviewed simultaneously on the same host computer screen; thus it is easy to create and check the data file. The second step is to classify postures from the data of joint angles and inclination angle by using discriminant functions. The classified postures and the video tape can also be reviewed simultaneously on the host computer screen. The last step in the analysis is to combine the data on work content, postures and EMG, and evaluate the workload from analyses of the time worked, types of postures, and level of the EMG in each step of work.

**DEMONSTRATIVE USE IN WORK MODEL**

A work model of manual baggage handling was carried out to collect sample data from a subject (male, 34 ys. height: 165 cm, weight: 58 kg) in the
Fig. 4. Lateral view of the setup and the work steps of the model. This work model consists of the following 6 steps:

- step 1: bring 15 bags near the platform (A→B).
- step 2: lift up the bags onto the platform (B→C).
- step 3: bring the bags to the far end of the platform (C→D).
- step 4: bring the bags to the near end of the platform (D→C).
- step 5: put down the bags on the floor (C→B).
- step 6: bring the bags to the start point (B→A).

All of the bags are the same size (size: 25×20×20 cm, weight: 7 kg), and have no special handles for holding. A subject carried out this 6-step work model twice at self-rating speed.

Fig. 5. Work time and posture at each work step. The total work time for all steps was 26 minutes and 7 seconds.
laboratory. The setup of the experimental room and the processes of the work model are shown in Fig. 4. The processes of the work model consisted of 6 steps; steps 1 to 3 are a baggage loading process, and steps 4 to 6 are a baggage unloading process. The video camera was fixed in the room to record a side view of the work. The goniometers were fixed on the right hip, knee and ankle joints so as to classify the postures of standing, forward bending and half sitting. The inclinometer was fixed on the right back of the upper body. The angle between the shoulder-hip line and vertical line was measured as the upper body inclination angle (straight standing: 0 deg). The electrodes of the EMG were fixed on the right low back at the level of L1-2.

The results are shown in Figs. 5-7. Steps 1, 2, 5 and 6 were similar in posture content (Fig. 5), but steps 2 and 5 were slightly harder than steps 1 and 6 according to the EMG results (Fig. 6). In steps 3 and 4, all of the postures consisted of forward bending and half sitting (Fig. 5), and the upper body inclination angles were nearly equal to 90 degrees (Fig. 7); thus a heavy posture workload existed in steps 3 and 4. Differences between the loading and unloading processes were assumed to occur only between steps 2 and 5, because of the differences in lifting up or putting down. However, there was not much difference between the steps according to the EMG results (Fig. 6). The subject had to hold the baggage before piling it, and could not do so quickly; thus the effect of lifting up or putting down the baggage might not have appeared in the EMG.

![EMG(μV)]

Fig. 6. Mean and S.D. of low back EMG (L1-2) of each work step. Numbers of samples of each work step were as follows: step 1 = 310, step 2 = 221, step 3 = 268, step 4 = 259, step 5 = 196, step 6 = 313.
DISCUSSION

There are many methods for the analyses of working postures. Image processing or ultrasonic positioning are often used for automatic data analyses\textsuperscript{12-15}). These methods are useful for rapid motion analyses such as computing three-dimensional positions, acceleration, angles, etc. However, these methods require special rooms or areas for collecting data, and it is impossible to apply them to the field studies in which workers move between rooms or floors. Thus these methods are usually applied to detailed analyses of some part of the daily work selected by overall surveys using direct observations or time studies. Our system, which uses a portable data collecting unit and a video camera, was developed to support such overall surveys.

Even if the automatic analyzing methods become more advanced, direct observations are still necessary for recording the points that require an understanding of job processes, i.e., classifying job steps, identifying unusual steps, finding the beginning or end points of job steps, etc. Video cameras are now widely used to support direct observations. It is easy to reduce error, supply missing data and eliminate bias between researchers by reviewing the video tape. But the burden of video tape transcription is heavy, making it necessary to use a support tool like our system.

One of the merits of using our system in the analysis of working postures is that it can grasp the characteristics of each work step. As shown in the sample data results, each step may have quite different characteristics. To improve working conditions, it is important to clarify the type of workload and the steps involved. The other merit of the system is that it can grasp events that have a

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{fig7}
\caption{Mean and S.D. of upper body inclination angles of each work step. Numbers of samples of each work step are equal to those in Fig. 6.}
\end{figure}
high workload but last only a short time. These events are important in preventing acute disorders such as back pain or sprain. Our system has a function that lists the durations of high-load work steps, making it easy to evaluate the workload of such short events.

In this study, we confined our improvements to the recording and analyzing of postures and EMG since we were attempting to investigate occupational low back pain and cervicobrachial disorders, which can be evaluated mainly by biomechanical measures. Many other kinds of data need to be measured for evaluations of whole body workload, mental stress, etc.\textsuperscript{16-19}. In these cases, the data should also be analyzed according to posture and work content, for precise, detailed evaluation. We will try to develop the capabilities of this system to enable it to measure more kinds of data according to the various types of work.

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