WorkerSense: Mobile Sensing Platform for Collecting Physiological, Mental, and Environmental State of Office Workers

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***Abstract*—In data collection of the human physiological and psychological conditions for mental healthcare (e.g., work engagement), measurement methods using environment-installed sensors and questionnaire surveys have been often used. However, these approaches are not practical in continuous data collection, due to the large burden for people. Recently, in association with advancing sensing technology with IoTs, sensing by small sensors and wearable devices has become possible easily. In this paper, we aim to establish a simple and general sensing method based on a mobile application for measuring physiological and psychological state of office workers and environmental state. Through the experiment for 2–3 weeks involving 60 office workers of four Japanese companies by using our application, we succeeded to create a dataset of physiological, environment, and mental state. This paper explains the developed mobile application, experimental procedure, and a summary of the data collected in the experiment.**

I. Introduction

As human physiological, psychological state and environmental condition have various influences on their mind and body, these data are widely used to improve performance and comfort. Especially, creating a workplace where they can work lively by understanding and supporting the mental and physical state of office workers is an urgent task for companies all over the world. To collect the psychological state in the workplace, the questionnaire survey is generally used. In Japan as well, the revision of the "Labor Safety and Health Act" in June 2014 has obliged regular checks of mental health at all companies with more than 50 employees. Hence, accurate management of working hours and stress checking is spreading year by year.

However, questionnaire-based measurement of stress level might be affected by subjective and psychological bias. In addition, the answer to such a survey may be influenced by events on the day before the survey date because of the difficulty of frequent collection due to the burden for people. Recently, in association with advancing sensing technology with IoTs [1], sensing by small sensors and wearable devices has become possible easily. Such sensing devices allow us to continuous data collection that can be used for estimating the result of questionnaire surveys. It has a big potential to improve the problem of the past questionnaires-based survey.

In this paper, we designed and developed a mobile application for measuring physiological and psychological state of office workers and environmental state in daily life. Also, we conducted experiments to collect data from 60 office workers of 4 companies. Finally, we succeeded to collect 4.5GB text data for 23 days in total. The response rate is varied by the time but around 65% subjects made answer by using our application.

In this paper, we describe our developed mobile application called *WorkerSense*, and report the collected data and remaining problem found out through the experiment.

II. Related Work

As a related work, our research group has proposed a HRQOL (health related quality of life) estimation method using smart devices [2]. In this research, we collect activity data (e.g., the number of steps, heart rate) and the answer to the existing questionnaire (WHOQOL-BREF [3]) related to daily QOL by using wearable device and smartphone. This method requires only a smartphone and a wearable device to estimate, and thus the experiment do not disturb participants' activities of daily living. We have confirmed its performance.

However, this method are not verified generality because of it uses data of only one participant. In addition, our research group use Empatica E4 wristband for a wearable device, the unit cost is $1,690. There is a problem of the cost per person (see: Table I).

III. Overview of Data Collecting System

Overview of WorkerSense system is shown in Fig.1. This system is composed of a smartphone application, a wearable sensor, an environmental sensor, and a server system which collects these sensor data. Participants always wear a wearable sensor for measuring activity, and carry an environment sensor for measuring the environment. In this paper, we have used

TABLE I

A COMPARISON OF PREVIOUS RESEARCH AND THIS RESEARCH

	Existing work [2]	WorkerSense
Number of participants	1	60
Attributes	Student	Office worker
Devices	Empatica E4[*a] ($1,690)	Fitbit Charge3 ($184)
environmental sensor usage	No	Yes
Survey methods	only HRQOL (WHOQOL-BREF)	Several common surveys for office workers (e.g., DAMS [4], Work engagement [5])
Frequency of survey	once/day	6 times/day

[*a] https://www.empatica.com/research/e4/

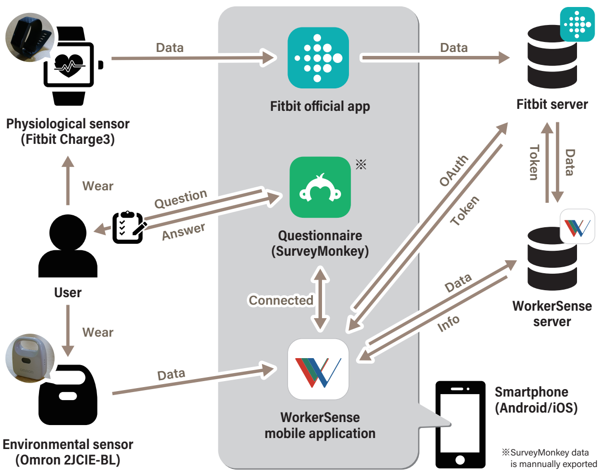

Fig. 1. Overview of data collection system

(a) Home (b) Settings

(c) Survey request (d) Survey response

Fig. 2. Screenshots of WorkerSense mobile application

Fitbit Charge3 and Omron 2JCIE-BL Environment Sensor respectively.

Then, using a smartphone application, we collect mental state data through multiple questionnaires, such as work engagement [5], recovery experience [6]. We provide a different combination of questionnaires on working days and holidays. The list of questionnaires used for WorkerSense is shown in Table II, and the detail explanation of questionnaires is provided as follows.

We have used standard occupational health questionnaires. DAMS is used to measure participant's feeling such as positive feelings, negative feelings, and anxious feelings [4]. Work engagement is evaluates the state of being active and energetic at work and ask how hard participants work [5]. Recovery experience measures for assessing how individuals unwind and recuperate from work during leisure time [6]. Productivity indicates the proportion of production to labor, and evaluate a performance of work. SAP (Subjective Assessment of Workplace Productivity) is an index of survey to measure the quality of work environment and intellectual productivity. On

TABLE II
OCCUPATIONAL HEALTH QUESTIONNAIRES

Questionnaire	Number of Question	Wake-up time 6:00		Morning 9:00		Noon 12:00		Evening 15:00		Night 20:00		Bedtime 21:00	
		W[*a]	H[*b]	W	H	W	H	W	H	W	H	W	H
DAMS [4]	9	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Work engagement [5]	3			✓		✓		✓		✓			
Recovery experience [6]	4			✓	✓								
Productivity [7]	2											✓	✓
SAP	4	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ADL	3		✓		✓		✓		✓		✓		✓
Task just before	10					✓		✓		✓			
Working day or holiday check	1	✓	✓										
How to spend lunch break	1									✓			
Review of the day	1											✓	✓
Total		14	14	20	20	26	16	26	16	27	16	16	19

[*a] Questionnaire on working day. [*b] Questionnaire on holiday.

the occasion of building our system, we newly added some categories, such as ADL (Activity of Daily Living), task just before, working day or holiday check, and so on.

Each screenshot of WorkerSense mobile application is shown in Fig.2. Participants can view the information of paired sensors on the home screen Fig.2 (a). They configure initial settings and confirm paired sensors on the setting screen Fig.2 (b). Daily surveys are distributed as push notifications and list on the screen Fig.2 (c). When participants select a survey, move to the survey response screen Fig.2 (d). We developed a management server for device connection and data collection. In a server system, we can manage/confirm survey distributing setting, the response status, and the acquisition status of each data We explain initial settings divide into following 3 steps. We prepared a manual for details of this process, and distributed it to participants.

Step1: User Registration
At first, participants register their name and mail address. These information are used for troubleshooting, and are not associated with an individual.

Step2: Registration of Fitbit Physiological Sensor
Data which measured by Fitbit physiological sensor are stored in the Fitbit server, and thus we cannot retrieve directly. Therefore, participants need OAuth authorization to get access token for data acquisition.

Step3: Registration of Omron Environmental Sensor
On the other hand, we can get data directly from Omron environmental sensors through BLE. Participants need to pair their sensor and smartphone application. After that, we can get environmental data regularly regardless of participants' operation.

IV. Experiment for Data Collection

We conducted the experiment to 60 office workers. Devices (Fitbit Charge3 and Omron 2JCIE-BL) and a mobile application are distributed to each participant. The experiment period is for two weeks basically. One company did for three weeks because they get interested in. The experimental schedule is shown in Fig.3. The Omron 2JCIE-BL is usually carried with a strap attached, and put near people when sleeping or bathing. A participant always wear the Fitbit Charge3 on non-dominant hands, except bath time. The questionnaires are distributed for six times per day (6:00, 9:00, 12:00, 15:00, 20:00, and 21:00) through the WorkerSense mobile application. The response deadline is set as four hours for questionnaires on 6:00 and 21:00, and one hour for others.

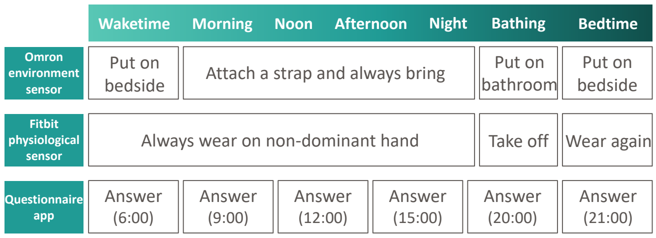

Fig. 3. Daily schedule of data collection

V. WorkerSenseDB

In this research, we asked 60 office workers in 4 companies to cooperate with our experiment to collect the actual data. Through the experiments explained above, we created *WorkerSenseDB*. Table III shows the attributes of participants (gender, age range, family structure, and period for data collection). Also, Table IV shows a summary of data collected using a smartphone, Fitbit Charge3, and Omron 2JCIE-BL during the experiment period.

We have picked up several data of each participant, and made statistic graphs shown in Fig.4. In the following sections, we describe the detail of data in *WorkerSenseDB*.

TABLE III
ATTRIBUTES OF PARTICIPANTS AND PERIOD FOR DATA COLLECTION

	Gender		Age range				Family structure		Total number of people	Period for data collection
	Female	Male	20's	30's	40's	50's	Single	Others		
Company N	3	6	2	3	3	1	2	7	9	Jan. 24 – Feb. 7, 2019
Company T	0	10	0	4	3	3	1	9	10	Jan. 30 – Feb. 13, 2019
Company F	2	14	1	3	6	6	3	13	16	Jan. 24 – Feb. 7, 2019
Company X	8	17	6	10	6	3	4	21	25	Jan. 31 – Feb. 14, 2019
Total	13	47	9	20	18	13	10	50	60	-

TABLE IV
PHYSIOLOGICAL AND ENVIRONMENTAL SENSOR DATA

Device	Data	Unit	Frequency
Smartphone	latitude	degree	1 sec
	longitude	degree	
	altitude	m	
	accuracy	m	
	orientation*a	degree	
	speed	m/s	
Physiological Sensor (Fitbit Charge 3)	Heart rate	BPM	1 sec
	Activity log*b	-	1 min
	Sleep log*c	-	1 min
Environmental Sensor (Omron 2JCIE-BL)	Temperature	°C	5 min
	Humidity	%RH	
	Illuminance	lx	
	UV index*d	-	
	Air pressure	hPa	
	Sound noise	dB	
	Discomfort index*e	-	
	Heatstroke index*f	°C	

*a North direction is set as 0 degrees, and it increases clockwise up to 360 degrees.

*b The activity log data including the number of steps, walking distance, burned calories, number of going up or down in elevation, sitting time, exercise time.

*c The sleep log including bedtime and wake-up time, sleep time length, depth of sleep.

*d The index which indicates the degree of influence of ultraviolet light on the human body defined in "WHO: Global solar UV index-A practical guide-2002."

*e The index (D) that indicates the degree of discomfort calculated by following equation with the values of temperature (T) and humidity (H).
$D = 0.81 \cdot T + 0.0 \cdot 1H \cdot (0.99 \cdot T - 14.3) + 46.3$

*f The index for preventing heatstroke, called wet bulb globe temperature (WBGT).

A. Physiological state

The statistic graphs of physiological state (sleep time and step counts, and sedentary time) is shown in Fig.4 (a). Large dispersion among participants has been confirmed, e.g., step counts are dispersed between 6,000–15,000. Such dispersion might be used for the analysis of the mental state of office workers, referenced to the result of Amenomori et al. [2].

B. Environment state

The statistic graphs of environment state (noise level and temperature, and humidity) is shown in Fig.4 (b). In this graph, we used data only 9:00–18:00 (general working time) on working day. We have confirmed a large difference in workplace environment among participants. Due to the workplace environment often effects on productivity or work engagement, this data should be useful for mental healthcare. Also, We have found differences in workplace environment among companies.

C. Mental state

We have collected answers for the questionnaire with a response rate of 65%. Fig.4 shows statistical graphs of work engagement and productivity. There are also a large dispersion, and individual differences of work engagement and productivity.

VI. FUNDAMENTAL DATA ANALYSIS

We analyzed the DAMS questionnaire as a fundamental analysis. DAMS is one of the index of surveys, and used to measure participant's feeling. It is evaluated by choosing from a scale of 0-6 (0=Strongly disagree, 6=Strongly agree) which of 9 words that express the moods (lively, gloomy, anxious, happy, obnoxious, nervous, cheerful, depressed, and worried). By using machine learning method, we established Balanced Random Forest model [8] for the binary predicting of depressive mood (high depression or low depression) measured from DAMS questionnaire on the wake-up time. The inputted features in machine learning model are about daily sleep data, which are obtained from Fitbit wrist-band, such as length of sleep a day, depth of sleep (e.g.Rem and Non-rem sleep), frequency of Rem sleep and so on. The number of features is thirteen items. In the results of leave one person out cross validation, F1 value, which is a well-known accurateness index of machine learning model, was 0.776 with the prediction of depressive mood. Moreover, a confusion matrix shown in Fig.5 indicates that our established model can predict depressive mood at the wake-up time from the sleep data of previous day.

VII. USABILITY ANALYSIS

Through this data collection experiment, several unexpected issues occurred regarding system use. In this section, we sort the issues and describe causes and system improvement.

The first issue, there are some input mistakes. Participants were allocated a unique ID, and need to input it in daily surveys. As an improvement plan, using QR code that protects anonymity and input mistakes.

The second issue, participants misidentified the application behavior. WorkerSense client has screen that display values of Fitbit physiological sensor to show the connection successful. WorkerSense client uses data that were obtained from Fitbit server, and thus it is not able to update data without data

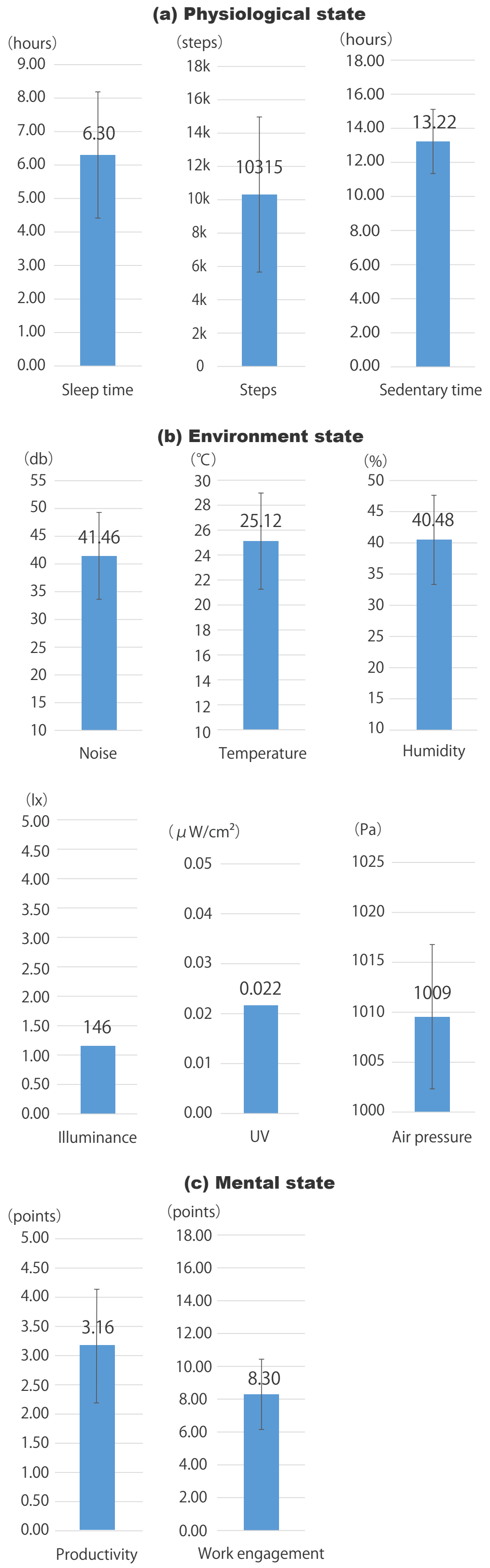

Fig. 4. Statistic graphs of data in WorkerSenseDB

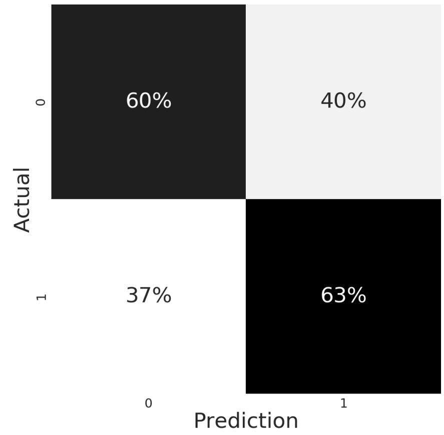

Fig. 5. Confusion matrix of the prediction for depressive mood

transmission by Fitbit official application. Therefore, participants thought that Fitbit data transmission failed. WorkerSense client Functional design need to make more simply.

The third issue, collecting data failed after omron environment sensor battery replacement. Participants were required sensor initialization after battery replacement, however, they used the sensor without noticing sensor initialization failed. WorkerSense application shows the sensor which participants have paired before, it is not the currently connected sensor. We need to display a dialog box when battery replacement to show participants the process for correct sensor initialization.

The four issue, data loss due to survey expiration. Each survey has a deadline to answer. However, there were who cannot use smartphone during work or did not notice survey distribution on the way home or stay home. We need to improve the timing of push notifications to increase survey response rates.

The five issue, the problem of respondent fatigue. It occurs when participants become tired of the survey task. Survey were distributed six times a day, there were repeated same questions. Especially, DAMS and SAP was contained all survey, participants were required to read same question text and answer it six times a day. As a result, participants might be tired or bored, and cause deterioration in data quality. Therefore, we need to improve to order of question not to bore participants.

VIII. Conclusion

Creating a workplace which makes office workers commit lively by understanding and supporting their mental and physical state becomes a hot topic in companies. However, continuous and long-term data collection from many office workers is not an easy task. In this study, we have developed a smartphone application for sensing of office workers' state. Through the experiment with 60 office workers for 2–3 weeks, we have created a dataset consists of physiological, environmental, and mental state of office workers. We published it as a public dataset for research community.

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