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Interactive Vital Measurement with Health Care Mobile Robots

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Abstract: The extension of health expectancy is getting a more important subject for developed countries with high rate of elderly population. In order to maintain the health of aged people living in care facilities, care staffs need to check the vital conditions of the residents frequently. For the facility staffs, however, taking vital signals of residents is one of the time-consuming tasks, and the operation is strongly expected to be supported by modern robot technologies. In this study, we propose an interactive vital measurement system with a health care robot. In the scenario of this interactive vital measurement, the health care robot operates its arm to reach the residents hand and requests the person to grab the handle, which we named as the haptic vital handle. The health care robot estimates the 3D positions of the body and the hand of the person based on the visual recognition. On the surface of the haptic vital handle, the vital sensors and pressure sensors are arrayed in order to detect physical gripping. The vital signals of the blood oxygen saturation (SpO_2) and heart rate (HR) are recorded by the vital sensors, when the mobile robot is confident of the hand gripping based on the detection of pressure patterns. We performed experiments to measure vital and pressure signals from healthy adults and evaluated the reliability of the measurement in the different configurations of the body postures denoted as the *stance, on-chair, on-wheelchair*, and *on-bed*.

Keywords: Vital Measurement, Heart Rate, Blood Oxygen Saturation, Health Care Robot.

1. INTRODUCTION

The shortage of care staffs for rounds in care and medical facilities is the major and urgent problem in aged-societies [1]. Due to the heavy load on the staffs, the incident rate caused by oversight is getting increased. The care staffs need to round in order to monitor facility residents in cabins with bringing many instruments and measurement devices to record vital signs. These kinds of physical tasks burden the staffs and make them exhausted. In our previous studies, we developed human-interactive robot Lucia for supporting the monitoring tasks by rounding in care and medical facilities [2]. Lucia is capable of moving in halls, corridors and cabins and interacting with facility residents and staffs in several operation modes. The monitoring ability of Lucia, however, was limited in simple human perception and their vital signals were passed over.

In literatures, several types of bed-side monitoring systems have been proposed [3]. This type of vision systems are usually fixed at the bed side, and therefore, the range of the view field is possibly limited. Once facility residents leave away from their beds, they are out of reach for monitoring. The bed-fixed vision systems are effective for monitoring severe bedridden patients, while the systems are insufficient for monitoring of active patients such as dementia patients with wandering symptoms. In contrast, interactive robots are one of the effective approaches to monitor active people in the facilities, since robots can round the space and actively access the moving people. In the active monitoring by robots, one of promising services is the measurement of vital signs. In previous studies, contactless breathing measurement systems using thermography cameras have been proposed [4][5], while the measurement signals influenced because of the drifting of the region of interest. The dependency of the body configurations for the measurement was not discussed sufficiently.



Fig. 1. Lucia, a health care robot, interacting with a wheelchair person by its arm.

In this study, we propose a new framework of interactive vital measurement with a health care robot, Lucia. In the scenario of this measurement, Lucia reaches its arm towards the persons hand and asks the person to grab the haptic vital handle located in the end of the Lucia arm. Figure 1 shows the Lucia interacting with a wheelchair person. Lucia perceives the 3D configuration of the body and hand of the interacting person based on the visual recognition. On the surface of the haptic vital handle, the vital sensors and pressure sensors are arrayed in order to detect physical gripping on the handle. The vital signals of the blood oxygen saturation (SpO_2) and heart rate (HR) are measured by the vital sensors. When Lucia feels confident of gripping on the handle, the recorded data of the vital signs is labeled as valid. This grip detection is based on the levels and patterns of the pressure sensing. We performed experiments of measuring vital signals and pressure signals with healthy subjects. We then evaluated the reliability of the vital measurement in four different

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configurations of the subject's body configurations denoted as *stance, on-chair, on-wheelchair*, and *on-bed*.

2. METHOD

2.1. Vital measurement system

We propose a vital measurement system based on a haptic vital handle. The basic idea of the vital measurement system is an integration of the physical sensing and the physiological sensing. In the physical sensing, we use force/torque sensors and touch sensors to capture haptic information from a person of the target. In the physiological sensing, we use the optical sensors to capture vital information from the person. In this framework, we make use of the haptic information to give reliability for physiological measurement. Actually, the vital measurement can be validated by touch sensing. This integration is considered effective to separate the errors of vital signal caused by the wrong measurement from the errors caused by the real physiological problem in health.

The haptic vital handle is a device designed for hand gripping. Figure 2 shows the haptic vital handle, which is equipped with 24 pressure sensors and 3 pulse oximeters. The main body of the haptic vital handle is made from the ABS resin (white parts). On the surface of the haptic vital handle, 8 strips of TPU elastomer (black parts) are arrayed to hold the 24 pressure sensors and the 3 vital sensors. The components made from the ABS and TUP are shaped by a 3D printer. The haptic and vital sensors are connected to either of 3 control boards contained inside the torso part of the haptic vital handle. The haptic vital handle is physically connected to the arm of Lucia.

Figure 3 show the transmission of haptic and vital information sampled in the vital measurement system. The haptic and vital information measured in the handle are transmitted to the PCs in Lucia passing through the CAN bus lines of the arm. Figure 4 show the contact detection based on a threshold value. The threshold value is calibrated based on the sensor values of the unloaded and maximal loaded.

2.2. Interactive arm for a health care robot

We propose an interactive arm for a health care robot. Figure 5 shows the 3D design of the arm and the assembled real arm. The arm is composed of three components denoted as the base, link and handle, where the handle was already explained above. The base component has a roll joint in the root, the link component has a pitch and yaw joint, and the handle component has a pitch and yaw joint too. The base roll joint is directly controlled by a motor. The pitch and yaw joints of the link and handle are controlled by the integration of the wire-driven control and joint lock/unlock control. This integration reduces the number of motors and motor drivers.

We assume that Lucia rounds in care facilities and on the way finds a candidate person of vital measurement. Lucia moves in the environment based on the field scanning with a LiDAR sensor, and finds a person using a depth camera. The configurations of their body postures can be various. We suppose four configurations of the facility residents who are standing on a floor, sitting on a chair, sitting on a wheelchair, and laying on the bed. When Lucia finds a candidate person, Lucia faces the person and presents an intention of vital measurement. If the person shows a welcome gesture, Lucia tries to approach the person and reach the person's hand with

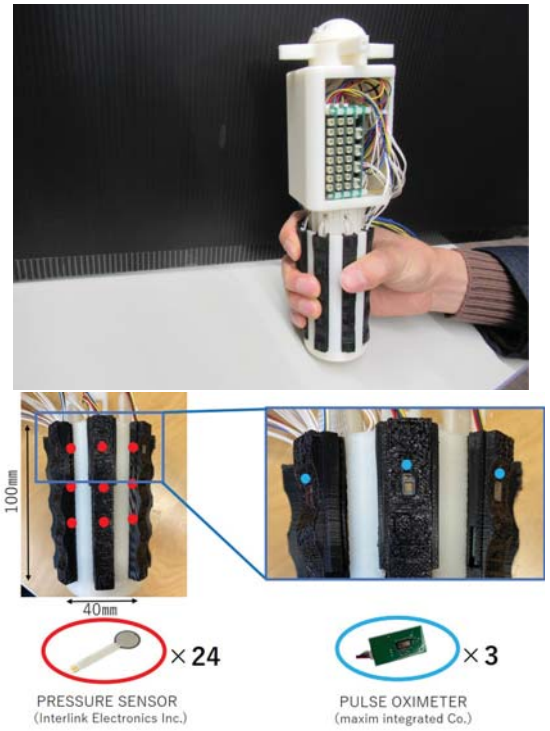


Fig. 2. The haptic vital handle equipped with pressure sensors and pulse oximeters.

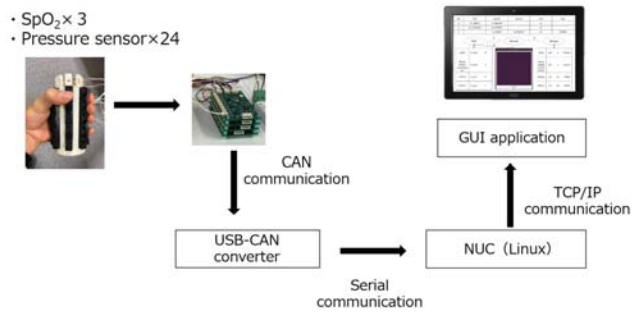


Fig. 3. The transmission of haptic and vital information.

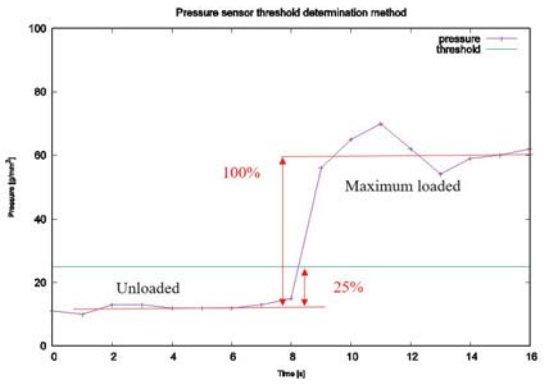


Fig. 4. Contact detection based on a threshold value.

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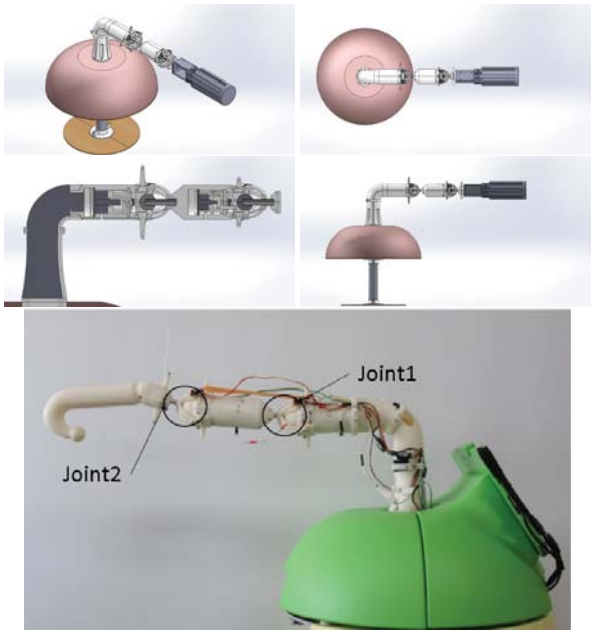


Fig. 5. 3D design of the arm and the assembled real arm.

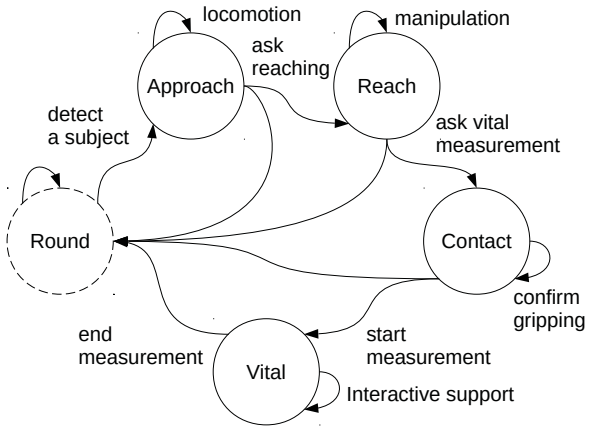


Fig. 6. The state transition model of Lucia when Lucia is demonstrating autonomous measurement of vital signs from faiclity residents.

its haptic vital handle. When Lucia detects pressures of gripping correctly, the system starts to record the vital signals until the end of measurement. The measurement takes about a few minutes. After the vital measurement, Lucia gives some words to the person and comes back to the regular rounds in the facility. Figure 6 shows the state transition model of Lucia, when Lucia is demonstrating autonomous measurement of vital signs from facility residents.

3. EXPERIMENTS

3.1. Vital measurement in the desktop environment

We performed experiments to measure vital signals and haptic signals of healthy adults. In the preliminary experiment, we demonstrated the measurement in a simple situation, where we used only the vital handle without the health care robot, and measured the vital signals in the desktop environment. Figure 7 shows the experimental environment

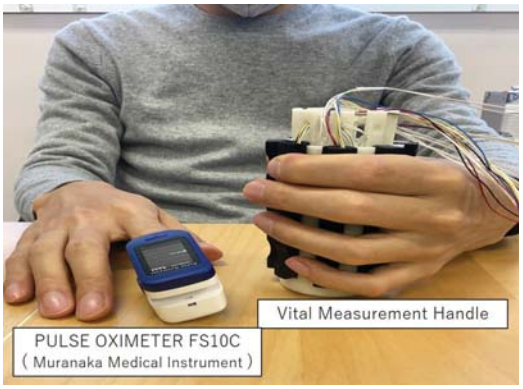


Fig. 7. The experimental environment to measure vital signals on the desktop.

to measure vital signals on the desktop. In this experiment, the subject is instructed to stop breathing for 90s. This disturbance can be observed as the trend of decrease and increase in the signal of SpO_2 and heart rate, respectively. Figure 8 shows the results of the measurement regarding the SpO_2 and heart rate with the corresponding contact maps. The vital measurement system output the similar trend of sequences in the two of three vital sensors. The trends were also similar to the values measured by the reference device of the pulse oximeter (Muranaka Medical Inc. FS10C). As shown in the contact maps, the contacts on the three vital sensors were detected. Therefore, the result of vital sensing and haptic sensing were consistent. In the experimental results, we confirmed that the vital sensing and haptic sensing were successful.

In the same environment, we performed experiments to detect contacts when shifting the grabbing position of the haptic vital handle. Figure 9 shows the maps of contact detection on the haptic vital handle. As shown in the corresponding photos, the contact maps represented the correct patterns of contact points. In all position of hand gripping, at least one vital sensor was contacted. This suggests that the vital sensing was robust for the position of hand gripping. Additionally, we demonstrated temporal sequences of gripping on the haptic vital handle. Figure 10 shows the sequential values of pressure sensors and the corresponding contact detection. The result suggests the possibility to encode the gripping patterns in the time domain. The temporal coding of gripping is considered effective for identification of the person who grabs the handle.

3.2. Vital measurement with a health care robot

After the preliminary experiments, we performed the interactive vital measurement using the health care robot, Lucia. We tried to measure vital and pressure signals in the four configurations of the subject body postures denoted as the *stance, on-chair, on-wheelchair*, and *on-bed*. Figure 11 shows the experimental environment. In the experiments, the interactive vital measurement was successful in the all configurations. Figure 12 shows the results of the measurement regarding SpO_2 and heart rate with different configurations

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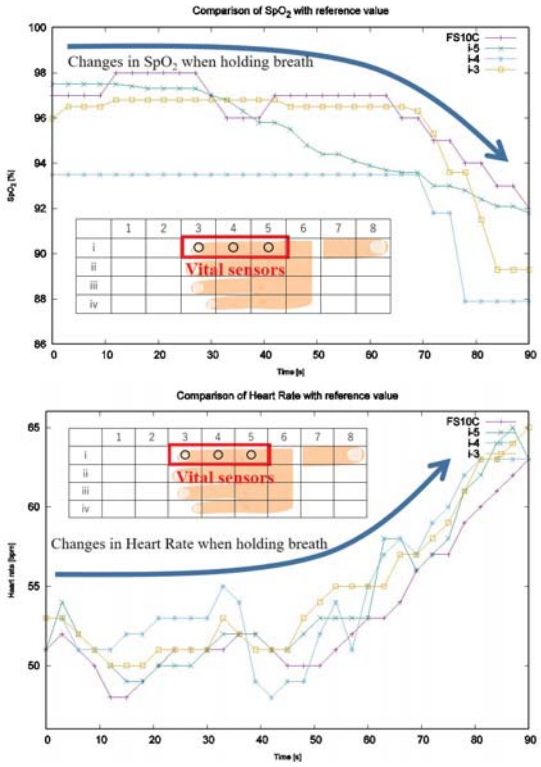


Fig. 8. Results of the vital measurement regarding SpO_2 and heart rate with the corresponding contact maps.

of the body postures. Even in case that the subject sat on the bed, Lucia could move into the narrow gap near the bedside and recorded vital signals.

3.3. Integration with breath detection

We integrated the proposed vital measurement system with the breath detection system developed in our previous study. Figure 13 shows a procedure for determining presence or absence of respiration from the obtained respiratory waveform. Fast Fourier Transform (FFT) is used for discrimination of breath. In the preliminary experiments, we confirmed that there was a significant spectral difference between the noise component and respiratory component. The time-series data of volume variation is converted into the frequency domain in every 10s, and the power spectrum is calculated. The determinant function of the breathing state is shown in eq.(1). k is the value obtained by dividing the maximum power spectrum by the spectrum average of the frequency domain over 1Hz. Based on the results obtained from the preliminary experiments, the verification experiment was conducted with a as 3.0 and b as 5.0.

$$P_r(k) = \frac{1}{1 + e^{-a(k-b)}} \tag{1}$$

We investigated the influence of human postures for the respiration measurement. In the experiments, we set the distance from the robot center to the target person as 125cm. In this experiment, we measured thermal point cloud (TPC) data from the different four posture such as the supine, prostrate and recumbent postures (two types with abdomen and

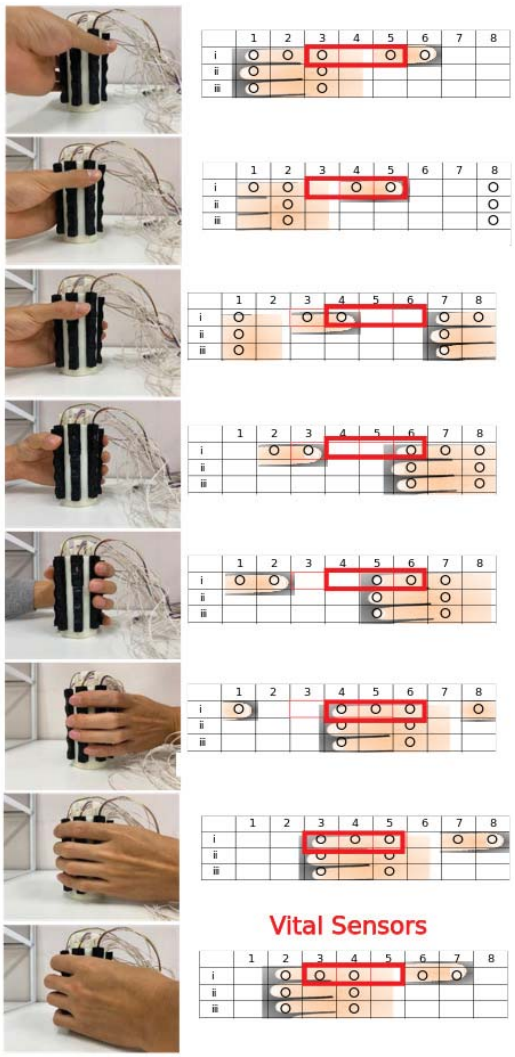


Fig. 9. Maps of contact detection on the haptic vital handle.

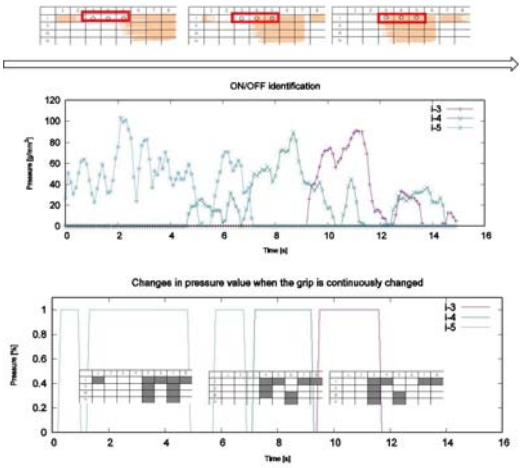


Fig. 10. The results of sequential values of pressure sensors and the corresponding contact detection.

back facing the vision system). Figure 14 shows visualized TPC data obtained from the four postures. Figure 15 shows the graph plotting the depth fluctuation for each posture in



Fig. 11. The experimental environment of vital measurement with a health care robot in the different configurations of the body postures denoted as *stance, on-chair, on-wheelchair*, and *on-bed*.

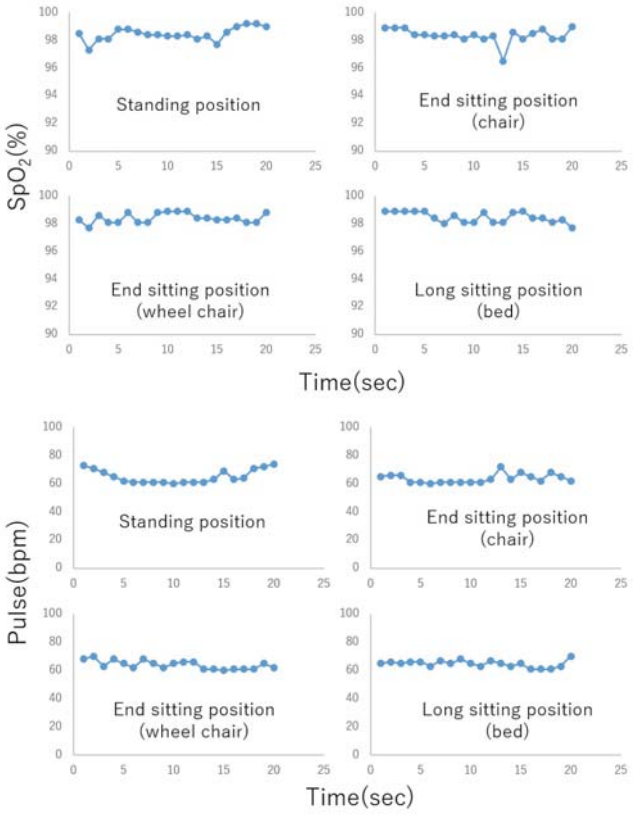


Fig. 12. The results of the vital measurement regarding SpO_2 and heart rate with different configurations of the body postures.

the time domain. Figure 16 shows the result of performing FFT analysis on the interval between 25s and 30s in the time domain. As shown in the figures, the temporal volume variation was correctly measured in any posture.

We simulated a situation of turnover incidents with a real human subject. We instructed the subject to fall down on the floor with the supine posture, and demonstrate breathing at 0.27Hz by listening to the metronome set at this frequency. The breath patterns for 30s and no-breath patterns for 20s were demonstrated for two times, respectively. The measured time series data and the result of autonomous discrimination is shown in Figure 17. The experimental results shows that the breath and non-breath patterns were successfully discriminated.

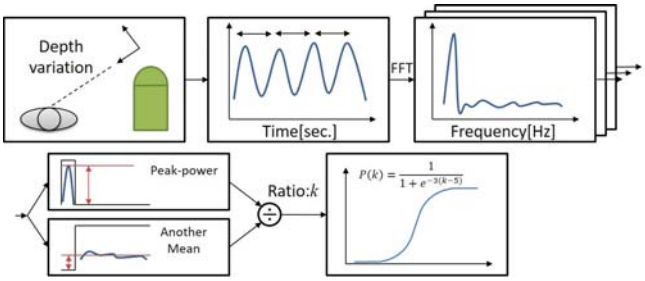


Fig. 13. The procedure of FFT Analysis.

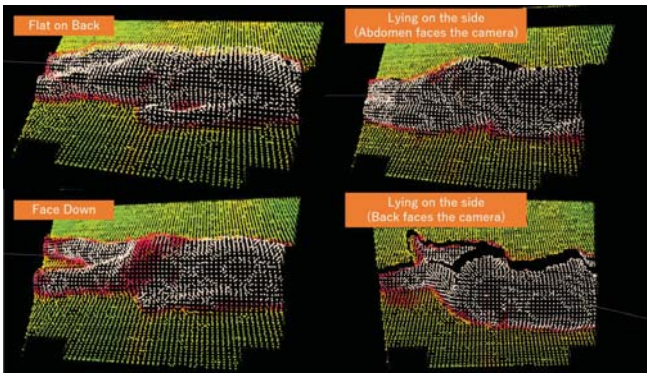


Fig. 14. TPC data with four different human postures.

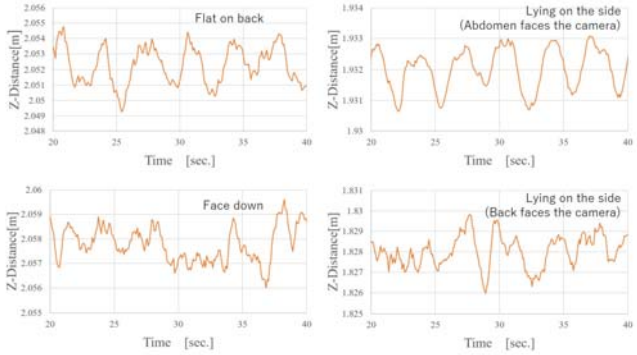


Fig. 15. Comparison by posture in the time domain.

We performed experiments to evaluate the discrimination of abnormal respiration patterns. In this experiment, we tried a simple diagnosis of respiration by simulating the breathing of tachypnea. We examined how the difference between the normal and abnormal respiration patters appear in the time domain and frequency domain measured by the proposed human measurement system. In this experiment, we regarded the normal range of the respiration as in (0.2 to 0.4 [Hz]). Figure 18 shows the result of the patterns. Apparently, we can see the difference of the peak locations in the frequency domain. This suggests the possibility of the autonomous discrimination from the contactless measurement performed by the rounding robot.

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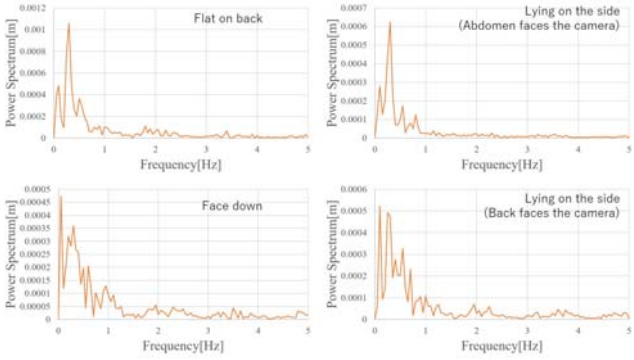


Fig. 16. Comparison by posture in the frequency domain.

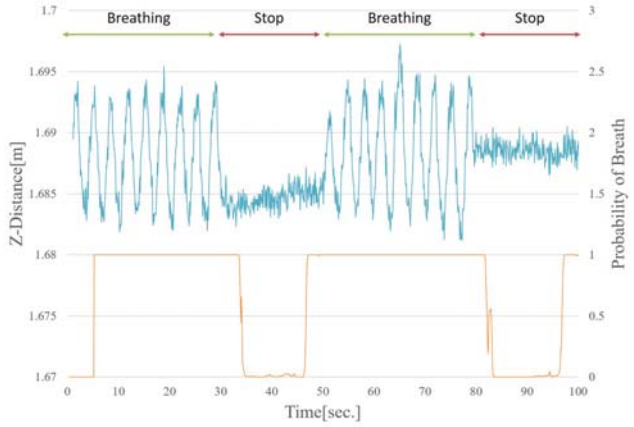


Fig. 17. Breath measurement and autonomous discrimination.

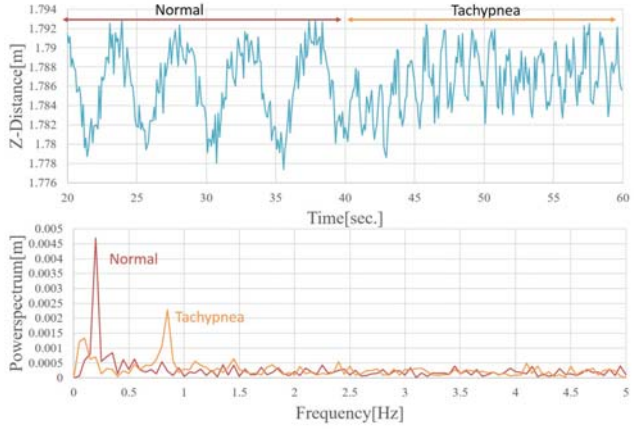


Fig. 18. Detection of Tachypnea breathing.

4. CONCLUSIONS

In this study, we proposed an interactive vital measurement system with a health care mobile robot. In the scenario of the interactive vital measurement, a health care robot, Lucia, operates its arm to reach the resident's hand and measured the vital signals. On the surface of the haptic vital handle, the vital sensors and pressure sensors are installed in order to detect physical gripping. The vital signals of the SpO_2 and heart rate were recorded by the vital sensors, when Lucia was confident of gripping on the haptic vital handle based on contact detection. We performed experiments to measure vital and pressure signals from healthy adults and evaluated the reliability of the measurement in the different configurations of the body postures denoted as the *stance, on-chair, on-wheelchair*, and *on-bed*. In the near future, we will integrate the proposed interactive vital measurement system with the fully autonomous round system of Lucia, and demonstrate the vital signal measurement in the real environments of care facilities.

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