A Depressurization Assistance System with a Suitable Posture for a Seated Patient on a Wheelchair

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***Abstract*— For reducing a risk of pressure sore caused by long period sitting on a wheelchair, a patient is required to depressurize buttocks by changing the posture suitably. Thus, we have been developed an automatic depressurization motion assistance system for a seated patient on a wheelchair. In our previous work, we developed a sitting surface coordination system which can lift or incline and assists a depressurization motion of a patient. However, in some cases, it is difficult to change his posture suitably for patients who do not have enough physical strength in their upper body using our proposed device. Therefore, in this paper, we propose a novel posture coordination assistance system for a wheelchair user. Our system consists of the adjustable sitting surface and novel proposed adjustable backrest. These two devices coordinate the sitting posture of the patient automatically. Our key ideas are two topics. One topic is mechanical design of the adjustable backrest for practical use. We realize small mechanism which enables easy implementation to a general wheelchair without special reconstruction. The other topic is a natural posture coordination scheme using the sitting surface and the backrest. We analyze buttocks depressurization operation by a nursing specialist and drive our proposed devices for realizing it. The performance of our system is verified by experiments using our prototype.**

Keywords—Depressurization motion assistance; Pressure sore; Adjustable backrest; Wheelchair

I. Introduction

In Japan, the population ratio of senior citizen who is 65 years old or more will exceed 27[%] at 2017 and rapid aging in Japanese society will advance in the future [1]. In aging society, the 23.5[%] of elderly person who does not stay at the hospital cannot perform daily life without nursing by other people [2] and the 14.6[%] maximum of them are suffering from the pressure sore [3].

Especially, the risk of the pressure sore using a wheelchair is serious for them because in many cases, they do not have enough seating positioning ability and it causes concentration of pressure on his sacral part [4]. For reducing this risk, it is required to change the seating posture for depressurization every fifteen minutes to two hours [5-7]. However, it is difficult for a nursing staff to help the patient for changing the seating posture at fixed intervals. Therefore, an automatic depressurization assistance system for the patient who uses a wheelchair is required.

In general, a special urethane cushion, which is designed for a wheelchair use, is widely used. However, these cushions cannot maintain the depressurization performance because the elasticity of urethane will lose under long-time usage condition [8]. A gel cushion is also used for the wheelchair user [8]. The gel is fluid, therefore, a gel cushion consists of a gel and a form material which covers a gel. Its performance depends on the shape of the form and a gel cushion with suitable shape has high performance for pressure distribution [9]. However, suitable shape is different individually and it requires tailor-made. Therefore, its cost tends to be expensive.

The previous researchers have been developed the air-cell cushion system [10-11] for the depressurization on the bed system. This system consists of plural air-cell cushions and the system switches high-pressure air-cells at fixed intervals. Using this scheme, the risk of pressure sore reduces because the pressure doesn't concentrate on a same part of the human body continuously. Using same idea, Murata developed the cushion system for the wheelchair [12]. This air-cell cushion is effective for depressurization on the sacral part of the wheelchair user [13]. However, these devices discuss on only the pressure of buttocks and these devices do not have a posture coordination function of the upper body of the user. Therefore, the user who does not have enough physical strength in an upper body tends to be fixed on a wheelchair and these devices depressurize his buttocks automatically without the user's intention.

Usually, we move our buttocks during sitting on the chair and this movement distributes the pressure on our sacral part.

This work was supported in part by Grant-in-Aid for Young Scientists B (23700676) from Japan Society for the Promotion of Science (JSPS).

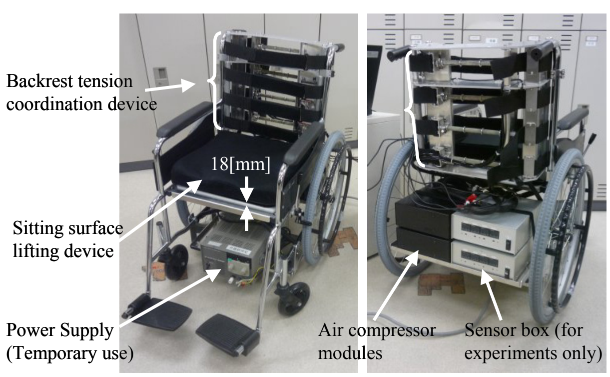
Especially, this movement concerns the daily action closely, for example, taking something from a desk. The positive daily action requires the elderly person to use own physical strength and it prevents the decrease his strength [14] and increases their QOL (Quality of Life). Therefore, these device are not suitable for the patient especially who has a remaining physical strength and we believe the depressurization system which assists the hip movement naturally with the user's intention is required for increasing their QOL.

Thus, in our previous work, we have been developed a sitting surface coordination system, which can lift or incline, and assists a natural depressurization motion of a patient [15]. However, in some cases, it is difficult to change his posture suitably for patients who do not have enough physical strength in their upper body using our proposed device and our device cannot depressurize his buttocks enough. Therefore, in this study, we develop a posture coordination assistance system for realizing a depressurization motion of a seated patient on a wheelchair. This paper is organized as follows: we introduce the mechanical design and controller of our system in section 2; we analyze the depressurization motion in section 3; we propose novel posture coordination scheme in section 4; we show the result of experiments using our prototype in section 5; section 6 is conclusion of this paper.

II. System Configuration

A. System Overview

Fig.1 shows overview of our proposed assistance system. Our system consists of a sitting surface lifting device [15] and a backrest tension coordination device. Its cushion on the top of the lifting device is a normal urethane cushion which are widely used on general wheelchairs (TC-046, Takano Co., Ltd.). These devices are designed for s general wheelchair which fulfills these standards (ISO7193, 7176/5). This means the user can built our system into their wheelchair without special construction.



(a) Front View (b) Back View

Fig. 1. Our prototype. Its weight is about 20[kg] without batteries. Our system is utilized on a general wheelchair (BM22-42SB, Kawamura Cycle Co. Ltd.) which fulfills Japan Industrial Standard (JIS T9201). JIS T9201 is almost equal to ISO7193, 7176/5.

B. Sitting Surface Lifting Device

Fig.2 and Fig.3 show our sitting surface lifting device. The sitting surface lifting device has four air-cells and they lift or tilt the sitting surface as shown in Fig.4. Each air-cell has an air compressor, a solenoid operated valve and an air pressure sensor. Using them, each air-cell is actuated for realizing the suitable inclination of the sitting surface. Furthermore, the acrylic resin prevents to shift the sitting surface.

Generally, the wheelchair should be coordinated for the patient individually, especially, the distance between the height of a seating position and the foot support is important [16]. Therefore, if the height of a seating position changes by a thickness of our assistance system, the patient will have to coordinate his wheelchair again. The thickness of our lifting device is only 18[mm] and the patient can use our device without re-coordination of his wheelchair.

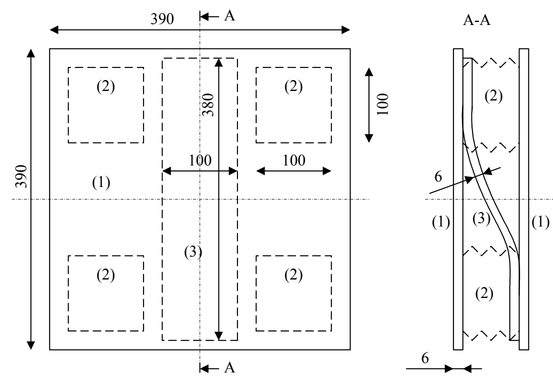
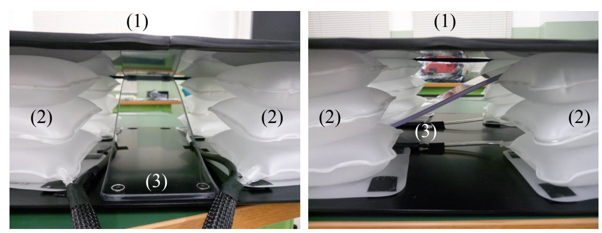


Fig. 2. Design of our proposed sitting surface lifting device. (1) is an aluminum base, (2) is an air-cell, (3) is an acrylic resin.



(a) Front view (b) Side view

Fig. 3. Air cells of our proposed lifting device.

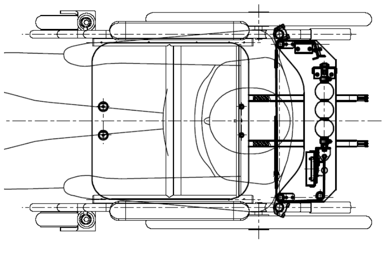
(a) (b)

Fig. 4. Lifting motion using four air cells.

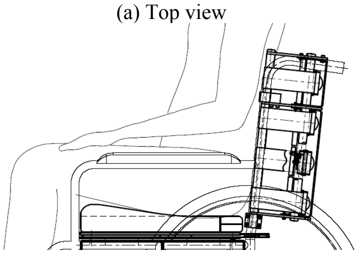
C. Backrest Tension Coordination Device

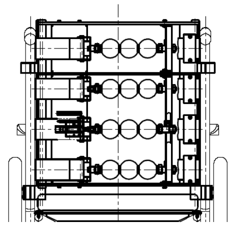
Fig.5 to Fig.8 show our backrest tension coordination device. Our device has four tension coordination modules as Fig.5. Each module has an artificial rubber muscle [17], an air compressor, a solenoid operated valve, a potentiometer which measures the contraction length of the artificial muscle and an air pressure sensor. Using them, each module coordinates the tension and the length of the backrest as Fig.7. Our system can support the backrest with about 200[N] load maximally and in our preliminary experiment, 100[kgf] patient does not exceed this load. Fig.8 is our prototype.

We design the position of a tension coordination module based on opinions of the nursing specialists. Their position can be changed with easy operation.



(a) Top view





(b) Side view (c) Back view

Fig. 5. Design of proposed backrest tension coordination device.

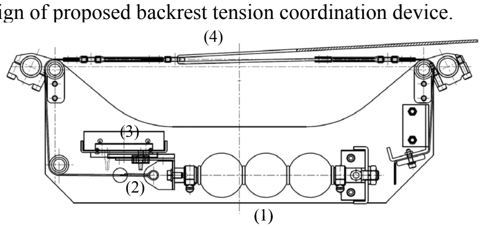
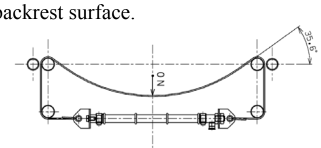
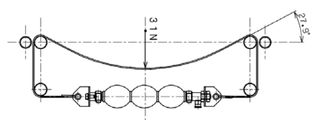


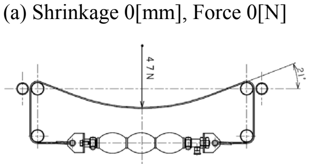
Fig. 6. The module of backrest tension coordination system. (1) is an artificial rubber muscle, (2) is a slider mechanism, (3) is a potentiometer and (4) is the backrest surface.



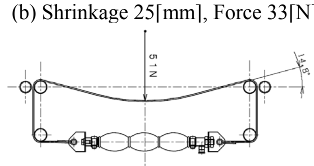
(a) Shrinkage 0[mm], Force 0[N]



(b) Shrinkage 25[mm], Force 33[N]

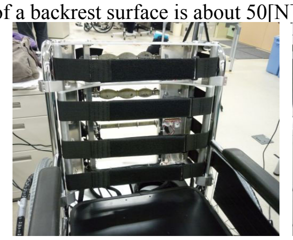


(c) Shrinkage 20[mm], Force 66[N]

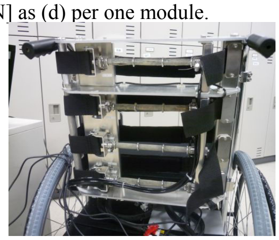


(d) Shrinkage 16[mm], Force 100[N]

Fig. 7. A motion of the backrest tension coordination system. The maximum load of a backrest surface is about 50[N] as (d) per one module.



(a) Front view



(b) Back view

Fig. 8. Our prototype backrest tension coordination device.

D. Controller

The sitting surface lifting device and the backrest tension coordination device are actuated by air compressors which are equipped on a bottom of the wheelchair. The sitting surface lifting device has four air-cells and each air-cell has a air compressor and a pressure sensor. As the same, the backrest tension coordination device has four an artificial rubber muscle and each muscle is actuated by one air compressor. These air compressors are modularized and our system has two air compressor modules for two devices. These modules have four air compressors (PFR32B28, OKENSEIKO Co., Ltd.) with solenoid operated valves and air pressure sensors in each compressor. These modules are same constitution and have compatibility with each other. Furthermore, these modules are waterproofing and small size as 200[mm] width, 80[mm] height and 240[mm] depth for practical use.

Our system requires 12[V] 2.8[A] power supply maximally for a posture coordination with a 100[kg] patient and standard batteries on a general powered wheelchair can supply it.

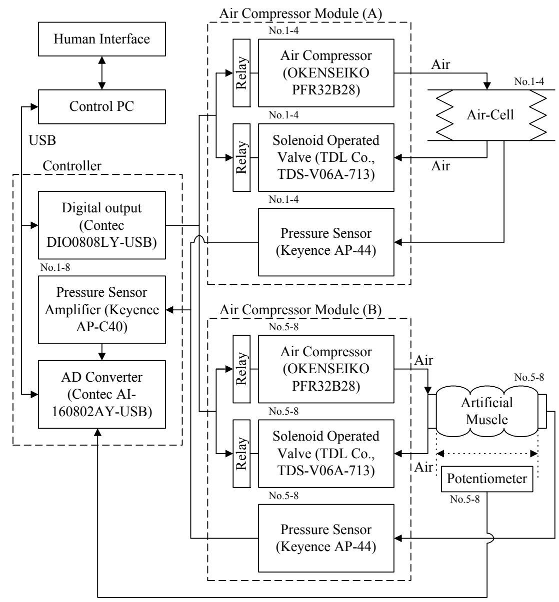


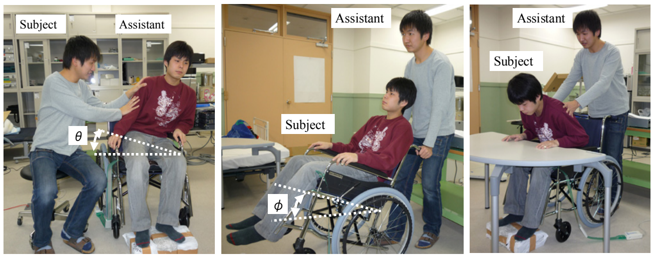
Fig. 9. A controller of our assistance system.

III. Depressurization Motion

A. The Depressurization Motion of Nursing Specialists

The nursing specialists recommend these depressurization motions for a patient as shown in Fig.10 [18]. In Fig.10(a), the subject inclines his body to right side or left side. This motion depressurizes the pressure of his hip on non-inclination side. The motion in Fig.10(b) requires the assistance by a helper. A helper inclines him with the chair to backward. In Fig.10(c), the subject grips the object in front of him (in general, a patient uses a desk.), and inclines his body to forward. We call the first motion is a motion A, the second is a motion B, the third motion is a motion C. These motions do not require large physical strength of the patient for operating them and it is useful for elderly wheelchair users. Furthermore, these motions are natural as the healthy person moves his hip during sitting.

In our previous study [15], the depressurization motion with the sitting surface lifting device is effective in a motion C, however, in a motion A and especially, in a motion B, in some cases, our system can not realize enough depressurization performance because a posture of the patient is not suitable. Therefore, in this paper, we discuss the motion A and the motion B and analyze them in next paragraph.

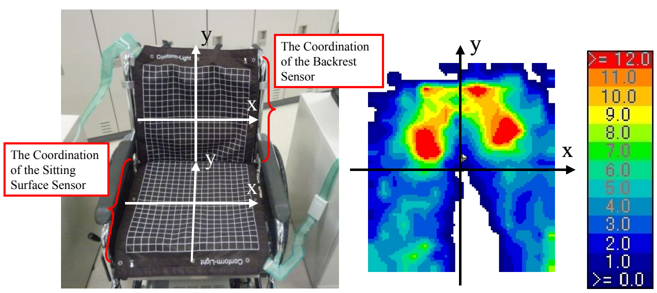


(a) Motion A (b) Motion B (c) Motion C

Fig. 10. The depressurization motion for a wheelchair user recommended by the nursing specialists [18].

B. The Evaluation Scheme of the Depressurization Motion

For analysis of the pressure distribution on the buttocks, we use two pressure distribution sensors (ConformLight, Nitta Corp.), which are putted on the sitting surface lifting device and the backrest tension coordination device as Fig.11(a). ConformLight has 360 pressure sensors on its sheet and can measure a pressure on each point. The measuring result when the subject sits on the sitting surface lifting device is shown in Fig.11(b). The pressures are expressed by colors. Red means strong (over 12[kPa]) and blue means a weak pressure.



(a) Two ConformLight sensors (b) Measuring results [kPa]

Fig. 11. The setup of the distribution pressure sensors and its coordination. The sitting surface and the backrest have each pressure sensor.

C. Analysis of the Depressurization Motion

In this paragraph, we analyze two depressurization motions assisted by other person's assistance based on a recommended scheme by the nursing specialists. We test two subjects, one is young and the other is elderly whose care level is 2.

In this preliminary experiment, the nursing specialist assists motion A and B. The subject sits on a general wheelchair and inclines his trunk according to the assistance. The position of its foot support is coordinated individually as [16]. The specialist judges the suitable inclination based on his experience and stops the assistance. We measure the pressure distribution and inclination of the wheelchair (θ and ϕ as shown in Fig.10) using an inclination meter.

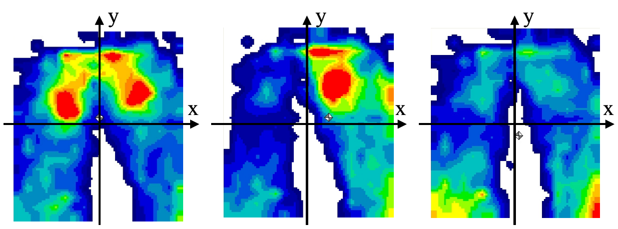
Fig.12 shows the pressure distribution of the hip during two motions. In general, the pressure which exceeds 64[mmHg] (=8.6[kPa]) increases the risk of pressure sore [19]. By the analysis results using Finite Element Method (FEM), the pressure should not exceed 10[kPa] [20] continuously. Therefore, we assume 8[kPa] is the high risk pressure area.

For evaluation of the effect of depressurization, we discuss the depressurization condition on the high-pressure area as (1). We call d in (1) as the depressurization ratio.

$$d = \frac{\sum_{k=0}^{n} b_k^{after}}{\sum_{k=0}^{n} b_k^{before}} \quad \left(if\ b_k^{before} < b_0,\ b_k^{before} = 0\ and\ b_k^{after} = 0 \right) \tag{1}$$

where b_k^{before} is pressure of sensor k in the ComforLight before the depressurization motion and b_k^{after} is pressure after the depressurization motion. In motion A, $k = 181, \cdots, 360$ and in motion B, $k = 1, \cdots, 360$. In motion A, depressurization area is only second and third quadrant (Right side in Fig.11(a)), therefore, we discuss only the pressure distribution on the left side. b_0 is threshold which shows the high pressure condition and in this study, we set 8[kPa].

From the results of the preliminary experiment, the pressure concentrated point which exceeds 8[kPa] shifts to the other part as Fig.12. Therefore, we can verify two motions depressurize the pressure concentrated area. Furthermore, Table 1 shows the depressurization ratio of two subjects. From these results, the depressurization ratio is approximately 20-30[%] and we use these values as an index of depressurization condition. The inclination in motion A is approximately 16[deg] and one in motion B is approximately 15[deg] in case of the young subject.



(a) Without assistance (b) Motion A (c) Motion B

Fig. 12. Pressure distribution with the depressurization motion by the nursing specialists in case of the young subject.

TABLE I. DEPRESSURIZATION RATIO [%]

	Young subject		Elderly subject	
	Motion A	Motion B	Motion A	Motion B
1st Trial	22.5	15.2	31.5	20.1
2nd Trial	28.7	16.4	33.4	18.6
3rd Trial	25.1	17.1	29.6	21.5
Average	25.4	16.2	31.5	20.1

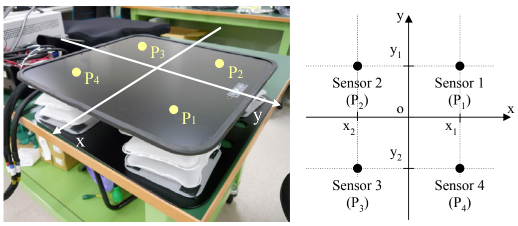
IV. DEPRESSURIZATION ASSISTANCE

A. Posture Measuring Scheme using our Proposed Device

For realizing the effective depressurization assistance, our system should assist the motion with suitable posture coordination according to the patient individually and it is necessary to measure the posture of the patient during the assistance. Generally, external sensors should be used for measure it, however, the additional sensors increase its cost. Therefore, we propose the measuring scheme for the patient's posture using only internal sensors.

1) The position of the center of pressure: The pressure of distribution on the sitting surface inflects the posture of the upper body. Therefore, we use the position of the center of pressure (COP) on the sitting surface for the upper body posture estimation as index. The COP (x_c, y_c) is derived from (2). The position and coordination of the pressure sensors which are equipped in the sitting surface lifting device are shown in Fig.13. $p_i(i=1,\cdots,4)$ are pressure values measuring by each pressure sensor in the air-cell.

$$\begin{cases} x_c = \{(p_1+p_4)x_1 + (p_2+p_3)x_2\} \Big/ \sum_{i=1}^{4} p_i \\ y_c = \{(p_1+p_2)y_1 + (p_3+p_4)y_2\} \Big/ \sum_{i=1}^{4} p_i \end{cases} \tag{2}$$



(a) The coordination on lifting device (b) The position of pressure sensors
Fig. 13. The position of pressure sensors and its coordination.

2) The applied load to the backrest: The applied load to the backrest also inflects the posture of the upper body and our system estimates the generated force by the artificial rubber muscle. Its generated force F is the function of the applied pressure P and the contraction length L as (3). [21]

$$F = \frac{P}{4\pi n^2}\left(3L^2 - b^2\right) \tag{3}$$

where n is a number of the carbon fiber which the artificial muscle uses and b is its length of the carbon fiber. These are parameters of the artificial muscle and it is difficult to detect them accurately. Thus, we detect the relationship between them by the preliminary experiment as shown in Fig.14. Our system can measure its pressure P and length L, therefore using the experimental results, our system can estimate the generated force F of the artificial muscle.

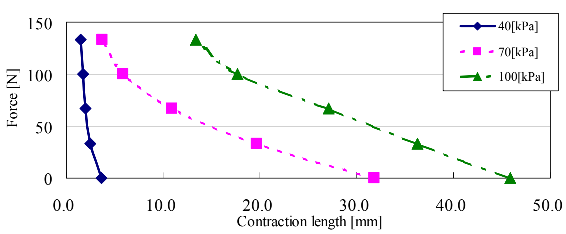
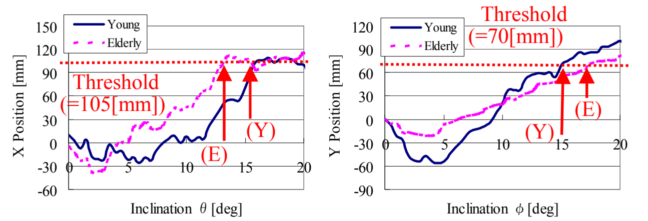


Fig. 14. The relationship between the generated force, the applied pressure and the contraction length of the artificial muscle.

B. Assistance of the Sitting Surface lifting Device

The sitting surface lifting device mainly generates the depressurization motion. Our system inclines the surface to x-direction in motion A and y-direction in motion B.

In our preliminary experiment, we measure the pressure distribution when the sitting surface inclines and derive the depressurization ratio as index of the depressurization condition. We define that when the depressurization ratio is less than 30[%] (Motion A) or 20[%] (Motion B, These values are derived according to the Table1), the depressurization is completed and our system judges the inclination at this time is suitable. Fig.15 shows the experimental result. From these results, we can verify that the COP is useful to evaluate the depressurization condition and our system continues to incline the sitting surface until the COP fulfills the threshold as Fig.15.

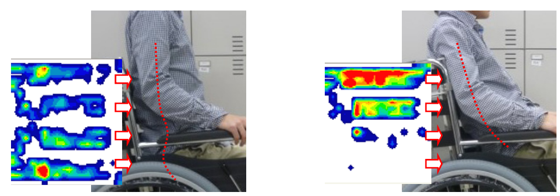


(a) Motion A (b) Motion B

Fig. 15. The position of COP during our system inclines the sitting surface. (Y) means the suitable inclination for the depressurization in case of the young subject and (E) is in case of the elderly subject.

C. Assistance of the Backrest Tension Coordination Device

The backrest tension coordination device maintains the upper body posture of the patient during the depressurization motion. In general, the back of the human is not flat and the backrest should be fit the curve of the backbone for holding the upper body of the patient. In our preliminary experiment by the elderly subject, the applied load to the backrests distributed when the patient maintains the suitable upper body posture, which straightened the back, by the instruction of the nursing specialist as Fig.16(a). In this case, the nursing specialist coordinates four backrest modules for fitting the subject's back. On the other hand, an unsuitable posture, which is a typical example, causes the pressure concentrated area as Fig.16(b).



(a) A suitable posture (b) A typical unsuitable posture
Fig. 16. The sitting posture and the distributed pressure on the backrest.

Thus, the backrest tension coordination device coordinates four backrest modules as follows. Before the depressurization motion starts, we set the suitable position of each backrest module which fits the suitable upper body posture of the user individually. (This part requires a manual operation and in our future work, we will develop an automatic coordination scheme.) Then, during the depressurization motion, our system distributes the applied load to each backrest module as (4).

$$P_i = \left(\sum_{i=5}^{8} F_i \Big/ 4 - F_i \right) \cdot k_p \tag{4}$$

where $P_i(i=5,\cdots,8)$ are control references of the pressure for each air-compressor and F_i is estimated applied load which is derived by (3). k_p is a coefficient.

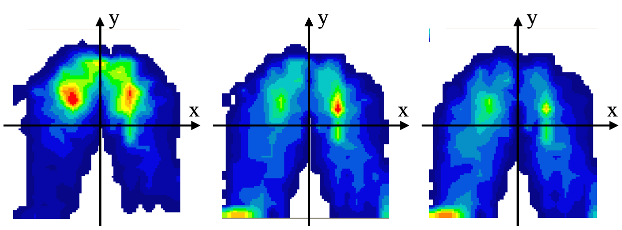
Using this scheme, if the applied load concentrated to one backrest module, it reduces the air pressure and its load shifts other modules. As the result, the pressure of the back is distributed and our adjustable backrest fits the shape of the back. Therefore, we can expect our system maintains the upper body posture of the user during the depressurization assistance.

V. EXPERIMENTS

For verify the effectiveness of our system, five elderly subjects whose care level is 1 or 2 test our prototype. We try three cases as follows. In case1, the nursing specialist depressurizes by motion A and motion B. In case2, we use only the sitting surface lifting device and in case3, we use all devices. Each subject tries them three times. The nursing specialist attended this experiment all times for safety reason.

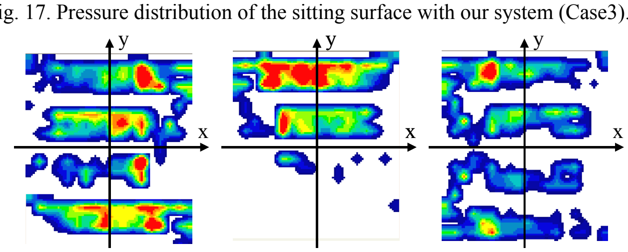
Fig.17 and Fig.18 show the pressure distribution map of the sitting surface and the backrest. In motion A, the pressure concentrated point of right side on his sacral part disappears in Fig.17(b). This means the right side of his sacral part is depressurized. As the same, we can verify that the pressure concentrated point disappears by motion B in Fig.17(c). From Fig.18(b), the pressure of the backrest is concentrated without the backrest coordination and in this case, the subject cannot maintain the suitable posture during motion B. On the other hand, its pressure is distributed using our backrest tension coordination device as Fig.18(c) and in this case, the subject maintains the suitable posture during motion B.

Fig.19 shows the depressurization ratio. From these results, the average depressurization ratio of case3 is larger than one of case2 and this means case3 is more effective for the depressurization. Furthermore, a variation of case3 is smaller than one of case2. Especially, a minimum value of case3 is improved greatly than case2. This means case3 always demonstrates the high performance of the depressurization. From these results, our novel proposed adjustable backrest and the posture coordination scheme with this device is effective for increasing the depressurization performance.



(a) Without assistance (b) Motion A (c) Motion B

Fig. 17. Pressure distribution of the sitting surface with our system (Case3).



(a) Motion A (Case3) (b) Motion B (Case2) (c) Motion B (Case3)

Fig. 18. Pressure distribution of the backrest with our system.

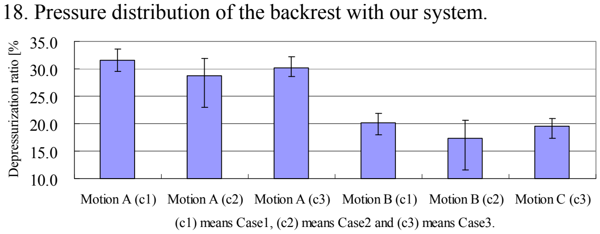


Fig. 19. The depressurization ratio of motion A and motion B.

VI. CONCLUSION

In this paper, we develop a novel adjustable backrest and propose the posture coordination scheme with it. Using this idea, the posture of the patient is coordinated suitability and our depressurization assistance system can generate the high depressurization performance stability. In our future work, we will develop the natural depressurization assistance scheme according to the user's intention.

ACKNOWLEDGMENT

This study received a generous support on the artificial rubber muscle from Prof. Taro Nakamura, Chuo Univ., Japan.

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