2011 IEEE International Conference on Rehabilitation Robotics
Rehab Week Zurich, ETH Zurich Science City, Switzerland, June 29 - July 1, 2011

A Depressurization Assistance Control based on the Posture of a Seated Patient on a Wheelchair

Daisuke Chugo[#] and Kazuya Fujita
School of Science and Technology
Kwansei Gakuin University
Hyogo, Japan
[#]chugo@kwansei.ac.jp

Yuki Sakaida
RIKEN-TRI Collaboration Center for Human-Interactive Robot Research (RTC)
RIKEN (The Institute of Physical and Chemical Research)
Aichi, Japan

Sho Yokota
Faculty of Science and Engineering
Setsunan University
Osaka, Japan

Kunikatsu Takase
Graduate School of Information Systems
The University of Electro-Communications
Tokyo, Japan

Abstract— **For reducing the risk of pressure sore caused by long period sitting on a wheelchair, we develop a depressurization motion assistance system which is low cost and suitable for practical use. Our developing system consists of a seating cushion which the patient sits on and four air cells which can lift or incline the seating cushion. Each air cell is actuated by small air compressor, which can drive using batteries on the wheelchair respectively, and each compressor has a pressure sensor on its body. In this paper, our key ideas are two topics. One topic is mechanical design for practical use. We realize thin mechanism which enables easy implementation to the general wheelchair. For realizing this thinly design, we develop the tilt mechanism using elasticity of acrylic resin and the controller which uses only pressure sensors for estimating its lifting height and inclination. The other topic is assistance control scheme based on the patient's depressurization operation for increasing a rehabilitation performance. For realizing the proposed control scheme, we analyze the hip depressurization operation by the nursing specialists and use its results for estimating the patient's condition. Using our system, the patient can depressurize by his own will on the general wheelchair easily. The performance of our system is verified by experiments using our prototype.**

Keywords- Depressurization Motion Assistance; Pressure Sore

I. INTRODUCTION

In Japan, the population ratio of senior citizen who is 65 years old or more exceeds 23[%] at January 2011 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 because the patient who uses it does 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 thirty minutes [5-6]. However, it is difficult for nursing staff to help the patient for changing the seating posture at half-hour intervals. Therefore, an automatic depressurization assistance system without other people's help 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 [7]. In previous works, for depressurization assistance, the air-cell cushion system is developed [8-9] for 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 same part of the hip continuously. Using same idea, Murata developed the cushion system for the wheelchair [10-11]. However, the air-cell system for wheelchair cannot reduce the pressure concentration as the bed type because the cushion area is smaller than one of the bed. Furthermore, in the case of seated patient, the wrong seating posture causes the pressure concentration on the hip of patient and the air-cell system cannot change his seating posture.

On the other hand, there are depressurization motions, which are recommended by nursing specialists [12]. If the required care level of the patient is slight (Usually, the patient who always uses the wheelchair is slight care level.), using these motions is useful because it requires the physical strength of patient. Using remaining physical strength of patient maximally has good effect for their rehabilitation and it prevents the decrease his strength [13]. Thus, the required function for the depressurization assistance system of the wheelchair is depressurization motion assistance which is based on the patient's will for using his remaining physical strength and maintaining assistance for stable seating posture.

Therefore, in this paper, we develop the depressurization assistance system for wheelchair elderly users whose care level is slight. Our key topic is the following. One is the mechanical

This work was supported in part by Grant-in-Aid for Young Scientists B (21700575) from Japan Society for the Promotion of Science (JSPS).

design which realizes low cost and easy to implement to the general wheelchair. The other topic is assistance control scheme based on the patient's will for the depressurization operation using his remaining physical strength for increasing a rehabilitation performance.

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 the new control 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. Assistance Mechanism

Fig.1 shows overview of our proposed assistance system. Our system consists of a lifting device with the special cushion designed for wheelchair and its controller. We design the lifting device as thinly as possible for easy to implement. Generally, the wheelchair is coordinated for the patient individually [6]. Therefore, if the height of seating position changes because of 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.

For realizing this thin design, we develop the tilt mechanism using elasticity of acrylic resin as shown in Fig.3 and Fig.4. Furthermore, there is no sensor in lifting device for realizing thin mechanism. The controller uses only pressure sensors which are equipped in the control box for estimating the lifting height and the inclination of our lifting device. We will discuss on the control system in next paragraph.

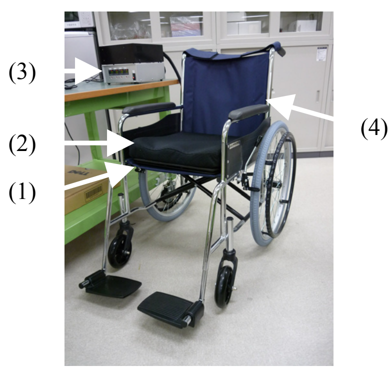


Fig. 1. Our prototype. Its weight is about 12[kg] without batteries. (1) is lifting device, (2) is wheelchair cushion (TC-046, Takano Co., Ltd.), (3) is air compressor and its control box and (4) is normal wheelchair. Our prototype requires an external power supply and control PC. In our future work, we will use batteries and built-in controller.

(a) Lifting device (b) Air compressor module

Fig. 2. Devices of our prototype.

The four air-cells, which have air-compressor respectively, lift or incline the aluminum base as shown in Fig.5. The acrylic resin prevents to shift this base. The acrylic resin can be used more than 20,000 times by its specification information from its manufacturer.

Our device can lift the 100[kgf] patient maximum. For realizing this performance, we choose PFR32B28 air compressors (OKENSEIKO Co., Ltd.). This compressor is small size and can generate more than 100[kPa] using 12[V] batteries. 12[V] batteries are used widely for electric wheelchairs in Japan and this means it is easy to implement this system on the general wheelchair.

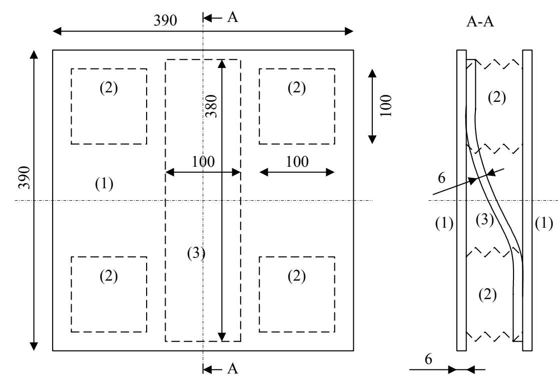
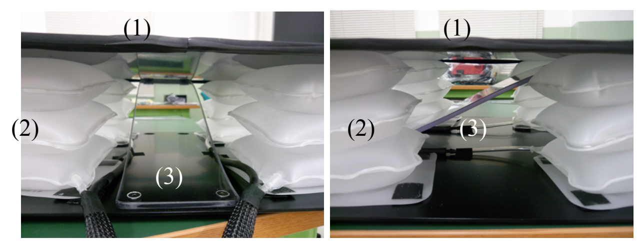


Fig. 3. Design of lifting device. (1) is aluminum base, (2) is air-cell, (3) is acrylic resin.



(a) Front view (b) Side view

Fig. 4. Lifting device.

(a) (b)

Fig. 5. Lifting motion using four air-cells.

B. Controller

Fig.6 shows our developed controller. Our controller consists of control box which contains the interface modules connected to control PC via USB and air-compressor module which contains air compressors, solenoid operated valves and pressure sensors. Both parts are small size as Fig.2 (b), 200[mm] width, 80[mm] height and 240[mm] depth. The controller requires 12[V] 2.8[A] power supply maximally for lifting the 100[kg] patient and the batteries on the general wheelchair can support.

Our system has four air-cells and each cell has an air compressor, a solenoid-operated valve and a pressure sensor.

For lifting the seating cushion, the system drives the air-compressors. On the other hand, for lowering it, the system stops the air-compressors and opens the solenoid-operated valves. The elasticity of acrylic resin helps the air-cell to shrink. Pressure sensors on each air-cell measure real-time and our controller uses the measuring data for derivation the lifting height using our developed scheme as odometry [14] and estimating the condition of the patient.

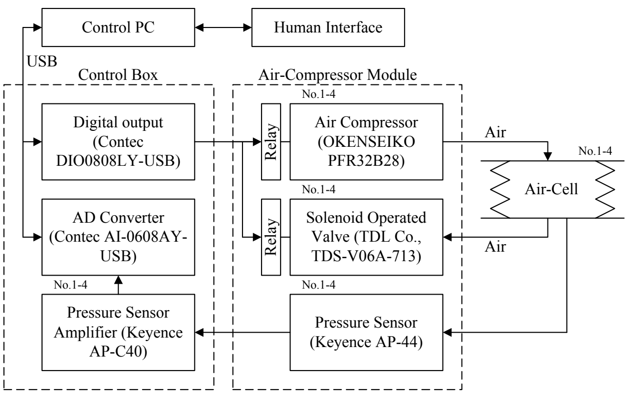


Fig. 6. Overview of our control system.

III. Depressurization Motion

A. The Motion by Nursing Specialists

Nursing specialists recommend these depressurization motions for the patient as shown in Fig.7 [10]. In Fig.7(a), the subject inclines his body to right side or left side. This motion depressurizes the pressure of his hip on non-inclination side. In Fig.7(b), the subject grips the object in front of him (in general, a desk is used widely.), and inclines his body to forward. The motion in Fig.7(c) requires the assistance by other people. The helper inclines him with the chair to backward. These motions do not require large physical strength of the patient for operating them and it is useful for elderly wheelchair user.

In this paper, we use these motions as references and analysis them in next paragraph.

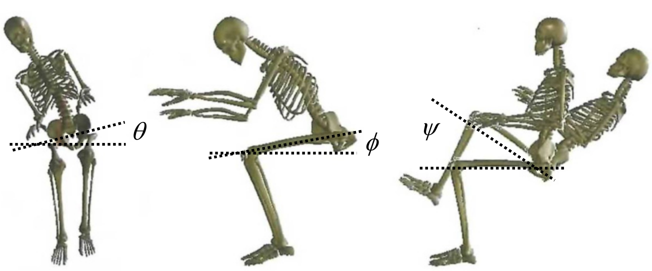
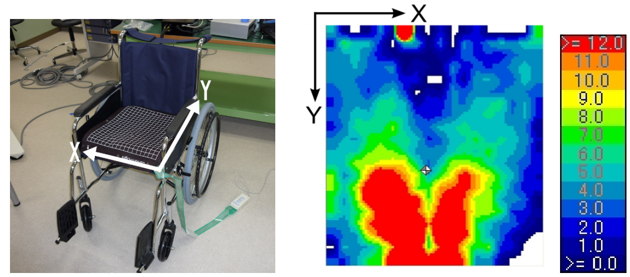


Fig. 7. The depressurization motion for wheelchair user recommended by nursing specialists [12].

B. Measuring System for Analysis

For analysis of the pressure on the hip, we use the pressure distribution sensor (ConformLight, Nitta Corp.), which is putted on our lifting device as Fig.8(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 it is shown in Fig.8(b). The pressures are expressed by colors. Red is strong (over 12[kPa]) and blue is a weak pressure.



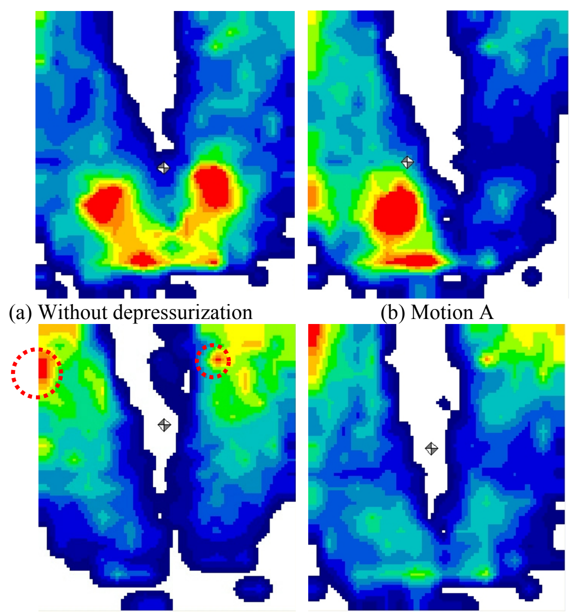
(a) ConformLight sensor (b) Measuring results [kPa]

Fig. 8. The setup of the distribution pressure sensor and its coordination.

C. Motion Analysis

In this paper, the motion in Fig.7(a) is called motion A, Fig.7(b) is motion B and Fig.7(c) is motion C. In this paragraph, we analyze three depressurization motions assisted by other people's help based on the recommended scheme by nursing specialists. We test two subjects, one is young and the other is elderly whose care level is 2. As the results, in each motion, θ is 15 [deg], φ is 13 [deg] and ψ is 21[deg] (mean value).

Fig.9 shows the pressure distribution of the hip during three depressurization motions. In general, the pressure which exceeds 32[mmHg](=4.3[kPa]) increases the risk of pressure sore [15]. By the analysis results using FEM, the pressure should not exceed 7[kPa] [16] continuously. In this experiment, the pressure concentrated point which exceeds 7[kPa] shifts to the other part. Therefore, we can verify three motions depressurize the pressure concentrated point.



(a) Without depressurization (b) Motion A

(c) Motion B (d) Motion C

Fig. 9. Depressurization performance of the motion by nursing specialists. In (c), wrinkle of sensor sheet makes red spots as the dashed line circle.

IV. Assistance Control

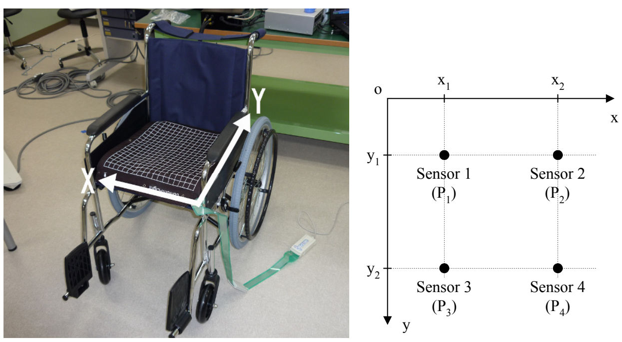
A. The Position of Center of Pressure

For realizing the automatic depressurization assistance, our system requires the patient's posture estimation without additional sensors. Especially, our system is required to estimates the following two topics.

- For increasing the rehabilitation performance, our system should start the depressurization assistance based on the patient's will. Thus, our system is required to estimate the starting signal of the motion.
- For realizing the effective depressurization assistance, our system should lift the seating cushion with suitable inclination for the patient individually. Therefore, our system should estimates it.

We assume these topics have relationship with the posture of the seated patient on our system. If the patient changes his posture during sitting on our system, the position of center of pressure (COP) on our system will change. Therefore, we use the position of COP for the condition estimation of the patient as index. The COP (x_c, y_c) is derived from (1). The position and coordination of pressure sensors are shown in Fig.10. $p_i(i=1,\cdots,4)$ are pressure values measuring by each pressure sensor in the air-cell.

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



(a) The coordination on wheelchair (b) The position of force sensors

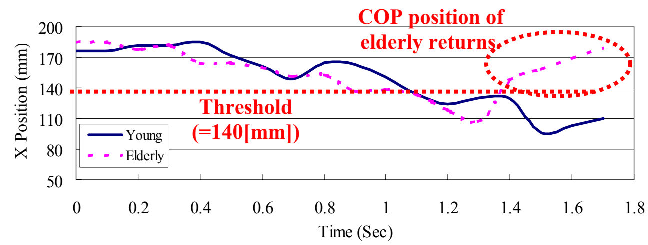
Fig. 10. The position of force sensors and its coordination. The center positions are x=195[mm] and y=195[mm].

B. Estimation of the Patient's Will

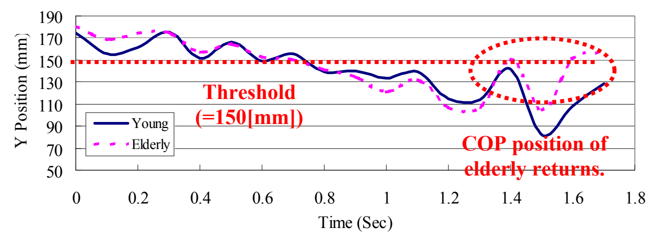
The first, we try to estimate the starting signal of the motion. In a preliminary experiment, we measure the position of COP when the subject starts these depressurization motions without assistance. The subjects are young male and elderly person whose care level is 2 in Japanese Long-term Care Insurance.

The experimental results are shown in Fig.11. Three motions show the tendency of movement when the subject starts each motion. When the patient inclines his body to right side (Motion A), the position of COP moves to right side from the center position of the lifting device (x=195[mm]) in both young subject and elderly subject as in Fig.11(a). In the elderly subject, the position of COP returns to the center position from 1.3 [sec] because the elderly subject does not have enough physical strength and he cannot incline his body with own physical strength continuously. However, when both subjects start a depressurization motion (Motion A), the positions of COP show same tendencies. Using them, our system can detect the will of patient who wants to start the depressurization motion.

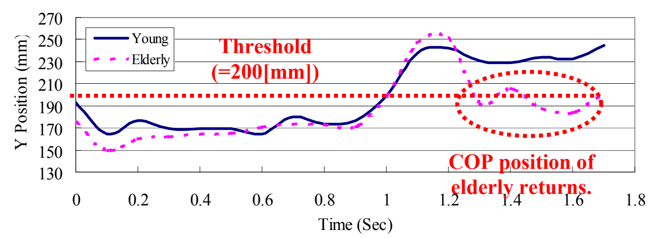
As the same, in motion B (Fig.11 (b)) and in motion C (Fig.11 (c)), there are same tendencies in the movement of the COP position. In motion B, the position of COP moves to forward direction in both young subject and elderly subject. On the other hand, in motion C, we can verify that the COP moves to backward direction. Thus, our system can detect the patient's will using them, too. In this paper, we set thresholds as shown in Fig.11 and our system detects the patient's will using them.



(a) Motion A



(b) Motion B



(c) Motion C

Fig. 11. The position of COP when the subject starts the motion.

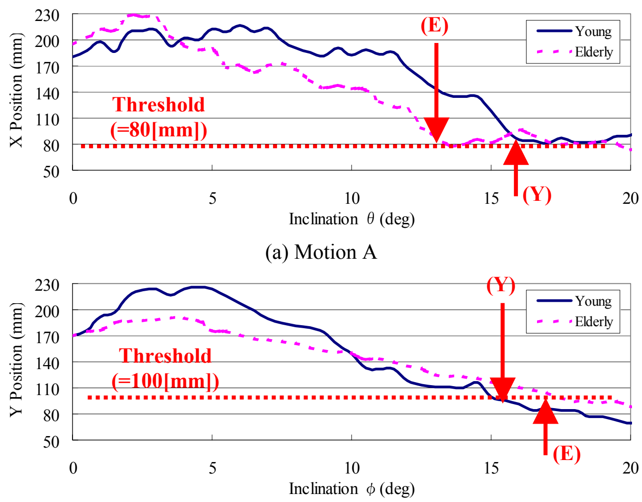
C. Estimation of the Suitable Inclination

The second, we try to estimate the suitable inclination of seating cushion which maximize depressurization performance. In a preliminary experiment, we measure the position of COP during our assistance system lifts the subject in motion A, B and C. At the same time, we measure the pressure distribution and we discuss the relationship between the inclination of each motion and pressure distribution. In this experiment, subjects are young male and elderly person whose care level is 2.

The experimental results are shown in Fig.12. In motion A (Fig.12(a)), the position of COP moves to right side from the center position of the lifting device (x=195[mm]) in both young subject and elderly subject according to the increases of its inclination. In both cases, when the depressurization is done enough, the position of COP is about 80[mm]. Thus, using this value as threshold, our system can detect the completing of the depressurization motion. In this experiment, the position of COP does not move less than 80[mm] because the subjects put their arm on the armrest when the inclination is large.

As the same, in motion B (Fig.12(b)), the position of COP moves to the front side and when the position of COP is about 100[mm], the inclination angle is suitable for depressurization effectiveness. Therefore, the system can use this value as threshold. However, in motion C, the position of COP does not move during assistance because the backrest holds the weight of patient mainly in motion C. Therefore, our proposed scheme is not useful in motion C and this is our future work.

Please note that these thresholds proposed in section 4.b and 4.c are different between the patients and in this paper, we set the threshold from the results of this preliminary experiment individually. In our future work, we will develop the threshold derivation system without individual experiment.



(a) Motion A

(b) Motion B

Fig. 12. The position of COP during our system inclines the seating cushion. (Y) means the suitable inclination for the depressurization in case of young subject and (E) is in case of elderly subject.

D. *Assistance Algorithm*

For using remaining physical strength of patient during the depressurization motions, we design the assistance control system based on the patient's will. Our proposed system realizes the interactive depressurization assistance as Fig.13. We consider the following requirements for designing the depressurization assistance algorithm.

- For safety reason, the patient must sit on the center position of the lifting device. Therefore, the first, our system detects the sitting position of the patient using the position of COP using (1). From the result of preliminary experiment, when the position of COP fulfills (2), the system recognizes that the patient sits on its center position.

$$(x_c - x_o)^2 + (y_c - y_o)^2 < k \qquad (2)$$

  where (x_0, y_0) is the center position of lifting device in the coordination as shown in Fig.11. In this case, the center position is $x_0 = y_0 = 195$ [mm]. k is coefficient and in this case, we set $k = 2500$ experimentally.

- For using the physical strength of the patient, our system waits the movement of the patient's body. When the system detects the symptom of the patient's movement, the system starts to assist the depressurization motion which he wants. Our system estimates the symptom of his movement and its direction using the threshold as shown in Fig.11. Our system can detect the small movement, therefore, if the patient does not have enough physical strength to incline his body completely, the system can estimate his will of the depressurization motion.

- By the opinions of subjects who are assisted by nursing specialists in section 3, the subjects often feel of fear in motion C. From the questionnaire results of them, the inclination to backward may cause this fear without enough previous notice to the motion assistance [17]. Therefore, before starting the assistance of motion C, the system announces it and asks the approval of the patient before starting the assistance.

- The assistance is based on the motion by nursing specialists which is recorded in section 3. In motion A and B, our system assists the patient based on the threshold as shown in Fig.12. In motion C, the system assists using the derived references (ψ is 21[deg]) in section 3 sequentially.

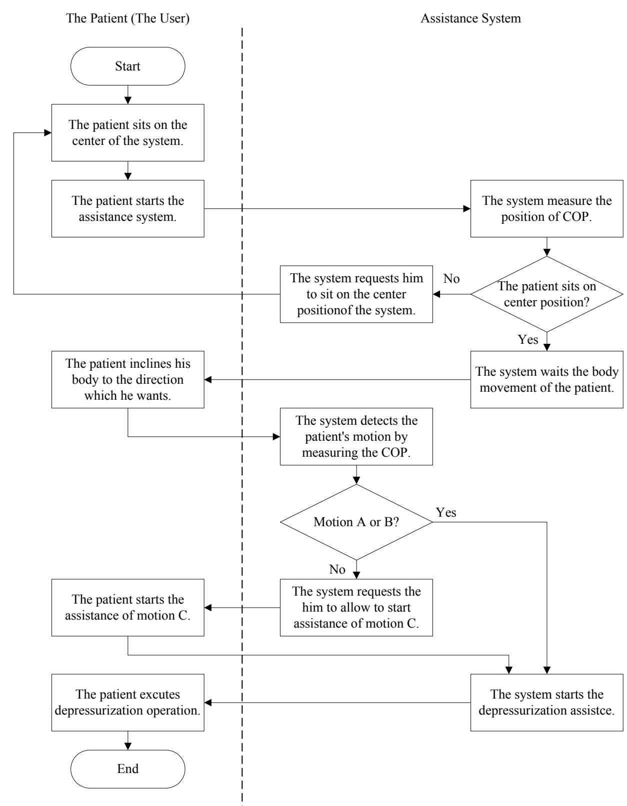


Fig. 13. Flowchart of proposed assistance scheme.

V. EXPERIMENTS

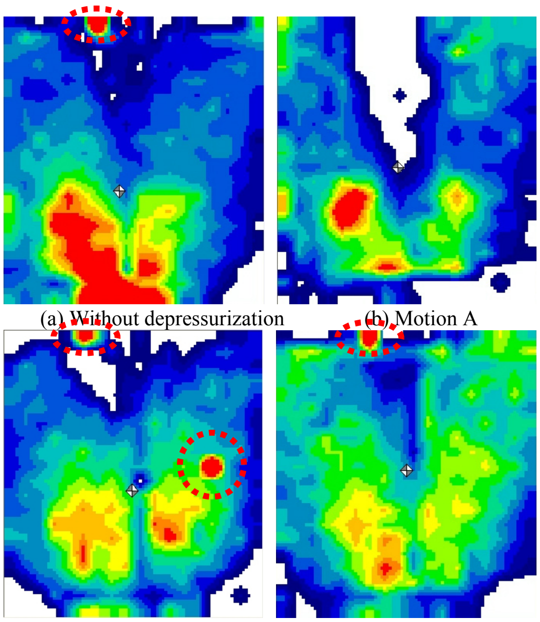
For verify the effectiveness of our system, three elderly subjects whose care level is 1 or 2 test our prototype. The subject operates depressurization motions using their physical strength based on their will and our system assists them. From preliminary experiments, we set the threshold as table 1.

As the results, system can assist the depressurization motions based on the patient's will. Fig.14 shows the pressure map. From Fig.14, we can verify that the pressure concentrated point shifts by the depressurization motions. Fig.15 shows the position of COP during assistance. From Fig.15, our system detects the beginning of the patient's motion and starts the depressurization assistance. Furthermore, system can detect the suitable inclination for depressurization without additional sensors. Therefore, our system is effective for depressurizations.

TABLE I. THRESHOLD

	Motion A	Motion B	Motion C
Subject A	(1) x=140 (2) x=90	(1) y=150 (2) y=100	y=200
Subject B	(1) x=140 (2) x=80	(1) y=130 (2) y=65	y=170
Subject C	(1) x=125 (2) x=70	(1) y=140 (2) y=95	y=200

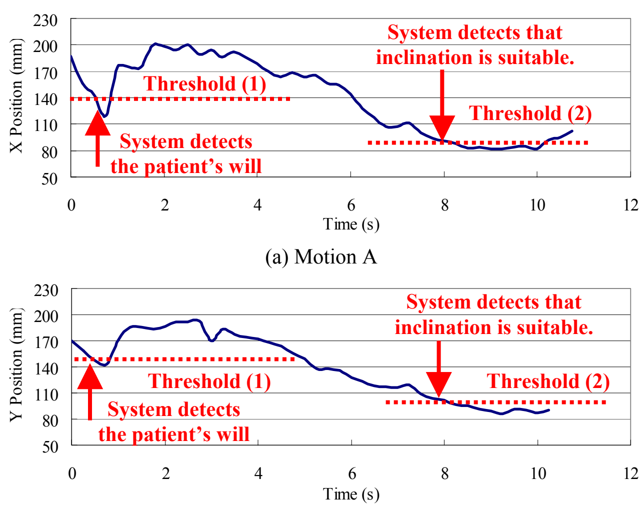
*(1) is for detecting the motion start and (2) is for estimating suitable inclination of the seating cushion for depressurization.



(a) Without depressurization (b) Motion A

(c) Motion B (d) Motion C

Fig. 14. The distribution of pressure using our assistance system (Subject A). The wrinkle of sensor sheet makes red spots as the dashed line circle.



(b) Motion B

Fig. 15. The position of COP during assistance. (Subject A)

VI. CONCLUSION

In this paper, we develop a depressurization motion assistance system for a wheelchair user. Our system is easy to implement for general wheelchairs. Furthermore, our system assists the motions based on the patient's will. This means the patient uses his own physical strength and it will bring a good influence for his rehabilitation.

At this time, our system uses the depressurization motion of nursing specialists sequentially as a reference. In our future work, we will develop the real-time posture estimation scheme of the patient and discuss the effective assistance motion based on the estimated posture.

REFERENCES

[1] Statistics Bureau, Ministry of Internal Affairs and Communications, Japan, "Population Estimates by Age (5-Year Group) and Sex of February 1, 2010," 2010. http://www.stat.go.jp/data/jinsui/tsuki/index.htm

[2] Ministry of Health, Labour and Welfare, Japan, "Annual Reports on Health and Welfare 2001 Social Security and National Life," 2001. http://www.mhlw.go.jp/toukei/saikin/hw/k-tyosa/k-tyosa01/4-3.html

[3] T. Oura, "Pressure Sores Caring and Movement of the Society," *Nursing Today*, Vol.13, No.2, pp.33-37, 1999. (in Japanese)

[4] T. Kurihara, T. Kinose, K. Ohtu, N. Okuyama and Y. Sakai, "A Study of Relation between Pressure Sores and Seating Positioning Ability in Wheelchair use by Elderly People," *The J. of Tokyo Academy of Health Science*, Vol.5, No.4, pp.258-262, 2003. (in Japanese)

[5] Agency of Healthcare Research and Quality, "Preventing Pressure Ulcers: A Patient's Guide," AHCPR Pub. No.92-0048, 1993.

[6] L. Guttmann, "New hope for spinal cord suffers," *Paraplegia*, Vol.17, No.1, pp.6-15, 1979.

[7] Y. Kono and K. Yoshikawa, "Introduction to Seating," Chuohoki Pub., 2007. (in Japanese)

[8] T. Defloor, DD. Bacquer, MH. Grypdonck, "The effect of various combinations of turning and pressure reducing device on the incidence of pressure ulcers," *Int. J. of Nursing Studies*, Vol.42, pp.37-46, 2005.

[9] H. Sanada, J. Sugama, Y. Matsui, C. Konya, A. Kitagawa, M. Okumura and S. Omote, "Rondamised controlled trial to evaluate a new double-layer air-cell overlay for elderly patients requiring head elevation," *J. of Tissue Viability*, No.13, pp.112-118, 2003.

[10] J. Murata, M. Ohyama, S. Murata, Y. Inai, S. Matsubara, K. Kaeriyama and H. Nishimura, "Development of alternating pressure cushion for a wheelchair," *Japanese J. of Occupational Therapy Research*, Vol.12, No.1, pp.17-20, 2009. (in Japanese)

[11] S. Kusuoka, S, Shibata and T. Yamamoto, "A pneumatic system aimed for reducing pressure control in back parts while driving an electric cart," *Proc. of 9th SICE System Integration Division Annual Conference*, pp.1309-1310, 2008. (in Japanese)

[12] Y. Miyachi and H. Sanada, "A new visual guide for pressure ulcers," Nagai Shoten Co., Ltd., 2006. (in Japanese)

[13] M. Hirvensalo, T. Rantanen and E. Heikkinen, "Mobility difficulties and physical activity as predictors of morality and loss of independence in the community-living older population," *J. of the American Geriatric Society*, Vol.48, pp.493-498, 2000.

[14] D. Chugo, K. Fujita, S. Yokota and K. Takase, "A Rehabilitation Robotic Cushion for Depressurization Assistance," *Proc. of 16th Robotics Symposia*, in press, 2011.

[15] E. M. Landis, "Micro-injection studies of capillary blood pressure in human skin," *Heart*, Vo.15, pp.209-228, 1930.

[16] MA. Curley, IS. Raznus, KE. Roberts and D. Wypij, "Predicting pressure ulcer risk in pediatric patients: the Braden Q Scale," *Nurs. Res.*, Vol.52, No.1, pp.22-33, 2003.

[17] W. C. Graafmans, M. E. Ooms, H. M. A. Hofstee, P. D. Bezemer, L. M. Bouter and P. Lips, "Falls in the Elderly: A Prospective Study of Risk Factors and Risk Profiles," *American J. of Epidemiology*, Vol.143, No.11, 1129-1136, 1996.