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Bio Rob 2006

**Pisa, Italy**
**February 20-22, 2006**

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# Force Assistance Control for Standing-Up Motion


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***Abstract* - In our current research, we are developing a power assistance system for standing up motion. Our developing system realizes the standing up motion using the support bar with two degrees of freedom and the bed system which can move up and down. In this paper, we develop the control scheme which realizes the natural standing up motion with fewer loads to the patient. For developing control scheme, we investigate the standing-up motion of aged people who requires to power support and typical standing up motion by nursing specialist. Comparing with two motions, we set the reference of standing-up motion with our system and we discuss the required assistance force during standing up. Our key ideas are two topics. One topic is control reference using zero moment point. Zero moment point is useful index which shows stability of the patient's posture. The other topic is combination of force and position control. According to the patient's posture during standing up, our control system select more appropriate control method from them. The performance of our proposed control scheme is experimented by computer simulations.**



***Index Terms – Force assistance, Standing up motion, Force control, Position control, Zero moment point***


## I. Introduction

In Japan, the population ratio of senior citizen who is 65 years old or more exceeds 20[%] at January 2004 and rapid aging in Japanese society will advance in the future. [1] In aging society, many elderly people cannot perform normal daily household, work related and recreational activities because of decrease in force generating capacity of their body. Today, the 23.5[%] of elderly person who is not in the hospital cannot perform daily life without nursing by other people. [2] For their independent life, they need daily assistance system which enable them to perform daily life easily even if their physical strength reduces.

Standing up motion is the most serious and important operation in daily life for elderly person who doesn't have enough physical strength. [3][4] In typical bad case, elderly person who doesn't have enough physical strength will cannot operate standing up motion and will falls into the wheelchair life or bedridden life. Furthermore, if once elderly person falls into such life, the decrease of physical strength will be promoted because he will not use his own physical strength. [5] Therefore, we are developing the force assistance system for standing up motion which prevents the decreasing of physical strength by using the remaining physical strength of elderly person maximum.

In previous works, many researchers developed power assistance devices for standing up motion. However these devices assist all necessary power for standing up and they do not discuss the using the remaining physical strength of patients. [6][7] Therefore, there is a risk of promoting the decrease of their physical strength.

Our assist system is shown in Fig.1. The system consists of support bar with two degrees of freedom and the bed system which can move up and down. We assume the patient sits down on the bed and grip the bar using his hand. The support bar and the bed system can operate cooperatively. The support bar has two force sensors on each degree of freedom and the elasticity element for reducing the impact when it contacts the other objects. [8]

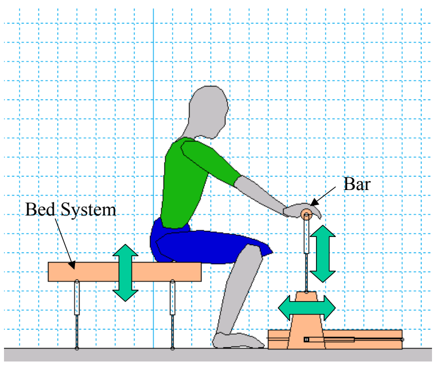



Fig. 1 System configuration

In this paper, we develop the control scheme on this system for realizing force assistance system which prevents the decreasing of physical strength by using the remaining physical strength of the patients maximum. Our key ideas are control reference using zero moment point and combination of force and position control. Using our control scheme, the patients can stand up with fewer loads and can use their own remaining physical strength during the motion. We verify the performance of the proposed control scheme through the computer simulations.

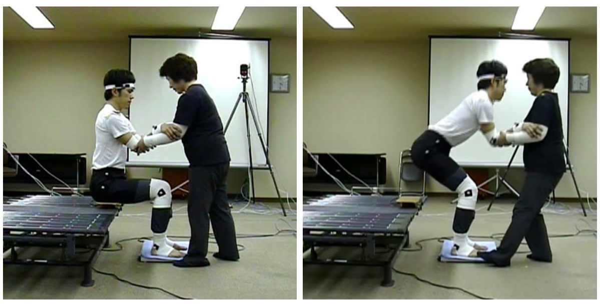
This paper is organized as follows: we introduce the typical standing up motion by nursing specialist and discuss the condition for realizing this motion in section 2; we propose the new control scheme and show the result of computer simulations in section 3; section 4 is conclusion of this paper.

## II. Standing Up Motion

### A. *Motion by nursing specialists*

In previous study, a lot of standing up motions for assistance are proposed. Kamiya [9] proposed the standing up motion which uses remaining physical strength of the patients maximum based on her experience as nursing specialist. Fig.2 shows the standing up motion which Kamiya proposes. In this study, we analyze this standing up motion and typical motion by elderly person. Comparing two motions, we discuss the following topics.

- Advantage of Kamiya's motion.
- The condition of dividing Kamiya's motion and typical motion by elderly person.
- The required condition for our assistance system.



(a) (b)

Fig. 2 Standing up motion by nursing specialist

### B. *Measuring Procedure*

In this study, we assume the standing up motion is symmetrical and we discuss the motion as movement of the linkages model on 2D plane as shown in Fig.3. [10] We measure the angular values among the linkages, which reflects the relationship of body segments. The angular value is derived using the body landmark as shown in Fig.3.

We measure two cases. Case 1 is standing up motion assisted by nursing specialist based on Kamiya's motion. Case 2 is standing up motion by elderly person who cannot stand up easily by own physical strength. In case 2, we measure the standing up motions of 5 persons (One man and four women from 72 to 84 years old) and use mean value.

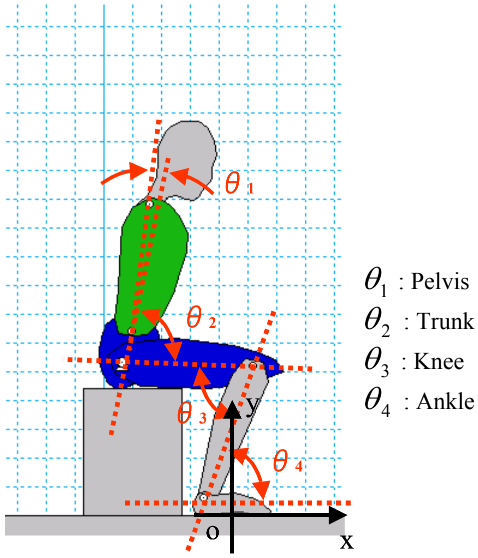


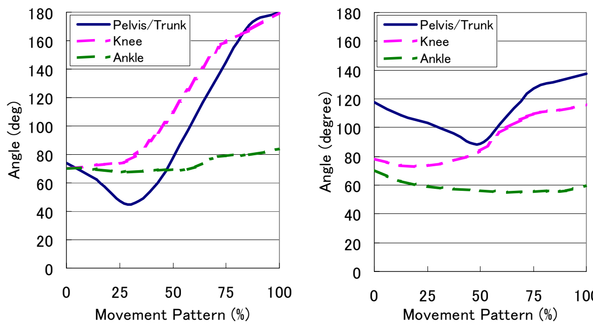

Fig. 3 Human model

### C. *Data Analysis*

We show the results of case 1 in Fig.4 (a) and the results of case 2 in Fig.4 (b). Y-axis shows the angular value (Pelvis and trunk, knee, ankle) and X-axis shows the movement pattern [10] which means the ratio of standing up operation. The movement pattern is derived from (1).

$$\hat{s} = \frac{t}{t_s} \tag{1}$$

where $t_s$ is required time to the standing up operation and $t$ is present time.




(a) With Kamiya scheme (b) Elderly person

Fig. 4 Standing up motion

Furthermore, Fig.5 shows the standing up motion with Kamiya's motion and Fig.6 shows the motion of elderly person.

From these results, we can obtain the following findings.

- In case 1, the movement of the body is larger than the movement in case 2 during standing up. Especially, the trunk is inclined to forward direction during lifting up from chair.
- In case 2, the angular values of knee angle and ankle angle are smaller than values in case 1. This means elderly person cannot extend his leg completely.

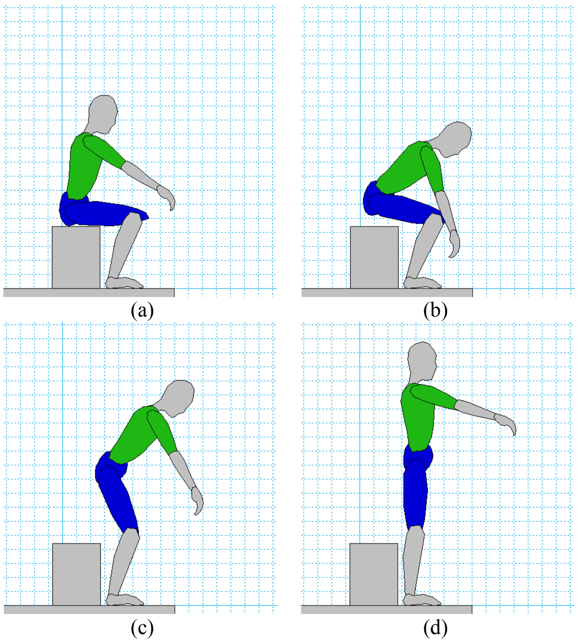


Fig. 5 Standing-up motion with Kamiya scheme

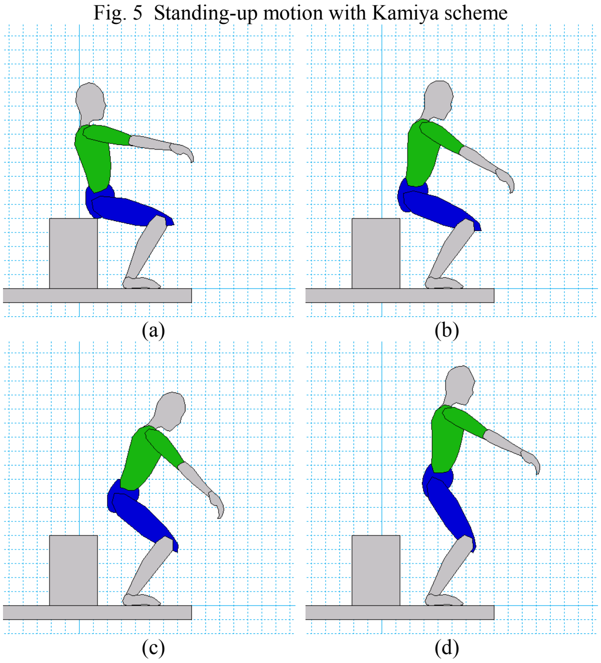


Fig. 6 Standing-up motion of elderly person

### *D. Stability on the motion by nursing specialists*

In previous paragraph, we obtain two findings comparing with standing up motion assisted by Kamiya's motion and the motion by elderly person.

One finding is inclining the trunk to forward direction with Kamiya's motion. In general, inclining the trunk reduces the load of knee during standing up [11] and this motion is useful for elderly person who doesn't have enough physical strength. However, typical elderly person doesn't incline the trunk during standing up as in case 2. We ask the 5 elderly persons in case 2 that why they don't incline their body to forward direction during standing up. Their answer is the fear of falling down. They say the balance of the body might be broken if they incline their trunk to forward direction. From this finding, the elderly persons cannot incline the trunk because it is required to maintain stably posture during standing up.

The other finding is elderly person doesn't extend his leg completely. In general, the posture without extending leg completely is easier to keep the balance of the body. [12] However, this posture puts a heavy load to knee. Therefore, from this finding, elderly person requires to maintain his posture even if the load increases.

From these discussions, we assume the condition of dividing Kamiya's motion and typical motion by elderly person is related to the balance of the body. Therefore, we use the position of the center of gravity and zero moment point (ZMP) [13] as index of stability. We derive the position of the center of gravity and ZMP using (2) and (3). The coordination is shown in Fig.3.

$$\bar{x} = \frac{\sum_{i=1}^{9} m_i \bar{x}_i}{\sum_{i=1}^{9} m_i} \tag{2}$$

$$x_{zmp} = \frac{\sum_{i=1}^{9} m_i(\ddot{y}_i + g)\bar{x}_i - \sum_{i=1}^{9} m_i \ddot{x}_i y_i}{\sum_{i=1}^{9} m_i(\ddot{y}_i + g)} \tag{3}$$

where $i\,(=1,\cdots,9)$ is identification number of the body segment, $\bar{x}_i$ is the position of the center of gravity in x-axis and $\ddot{x}_i, \ddot{y}_i$ are acceleration of the center of gravity on the body segment in x-axis and y-axis, respectively. $m_i$ is mass of the body segment and $g$ is gravitational acceleration.

The parameters are chosen from standard body data of adult male [14] as shown in Table 1.

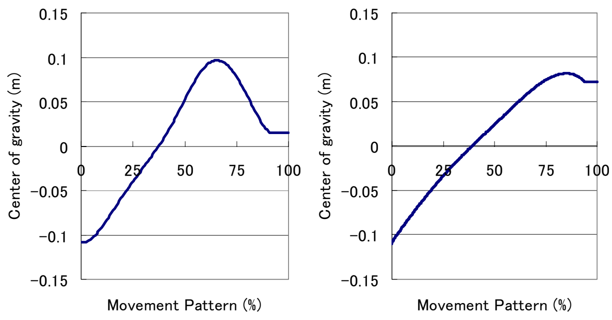
Table 1 Human parameters

| Number | Link Name | Mass [kg] | Length [m] | Width [m] |
|---|---|---|---|---|
| 1 | Head | 5.9 | 0.28 | 0.21 |
| 2 | Trunk | 27.2 | 0.48 | 0.23 |
| 3 | Hip | 18.1 | 0.23 | 0.23 |
| 4 | Humerus | 4.5 | 0.39 | 0.12 |
| 5 | Arm | 2.7 | 0.35 | 0.08 |
| 6 | Hand | 0.5 | 0.2 | 0.07 |
| 7 | Femur | 9.1 | 0.61 | 0.17 |
| 8 | Leg | 4.5 | 0.56 | 0.16 |
| 9 | Foot | 0.8 | 0.26 | 0.11 |

Fig.7 (a) shows the position of the center of gravity in case 1 and Fig.7 (b) shows the position in case 2. As the same, Fig.8 (a) shows ZMP in case 1 and Fig.8 (b) shows ZMP in case 2, respectively. The coordination of Fig.7 and Fig.8 is defined as shown in Fig.3. The length of foot is 0.26[m], therefore, if these positions are within $\pm 0.13$ [m], the posture is stability.

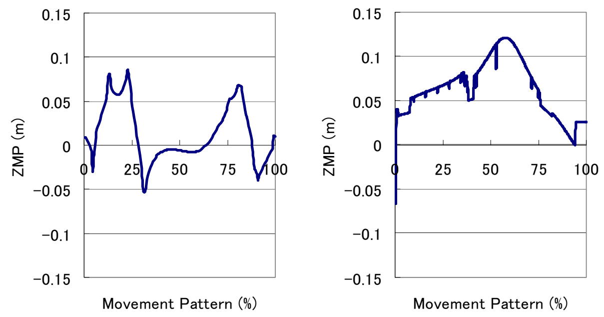
In case1 and case2, the position of the center of gravity moves from the heel to the foot ahead and they are same tendencies in Fig.7. At end of standing up motion, the position of center of gravity is on the foot ahead in case 2, because elderly person cannot extend his leg completely.

On the other hand, ZMP shows the different tendencies in case 1 and case 2 clearly. In case 1, ZMP moves quickly from foot ahead to heel around 25[%] of movement pattern in Fig.8 (a). In case 2, ZMP moves only around the foot ahead. Furthermore, in case 1, ZMP locates on the center of foot and this position is more advantageous for stability posture. From these results, ZMP has difference between case 1 and case 2 clearly and we assume moving pattern of ZMP is condition for realizing Kamiya's motion.




(a) With Kamiya scheme (b) Elderly person

Fig. 7 Position of gravity




(a) With Kamiya scheme (b) Elderly person

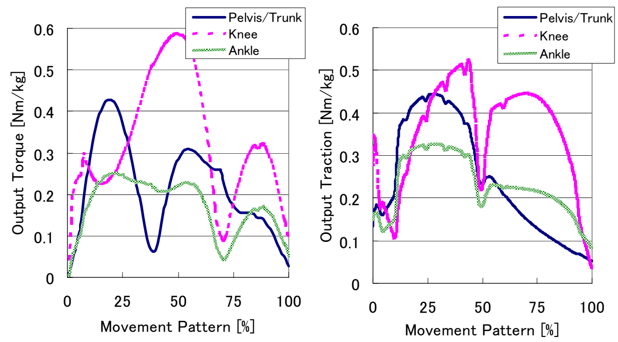
Fig. 8 Position of Zero Moment Point

*E. Required assistance for realizing Kamiya's motion*

In previous paragraph, we find the condition for realizing standing up motion by nursing specialist. In this paragraph, we discuss the required assistance for this motion. Now, we verify the required torque of each joint for realizing standing up motion of case1 and case 2 using computer simulations. Simulation parameters are chosen from Table 1. From simulation results, Fig.9 (a) shows the required traction of each joint in case 1 and Fig.9 (b) shows the position in case 2. Table 2 shows the maximum values of traction output and required power through the motion in each case.

Comparing with the results of case 1 and case 2, in case 1, required power for standing up is smaller than one in case 2 as shown in Table 2. Furthermore, in case 1, maximum values of traction output are smaller on pelvis and ankle joint. From these results, Kamiya scheme is effective to enable standing up motion with smaller load.

However, knee load of case 1 is heavier than one of case 2. In Fig.9 (a), knee load becomes heavy from 25 to 50[%] of movement pattern. During this period, ZMP moves quickly from foot ahead to heel in Fig.8 and it is important to realize standing up motion of Kamiya scheme. In general, if knee load is heavier than 0.5[Nm/kg], it is difficult to stand up for elderly person. [15] Therefore, standing up motion of Kamiya scheme is difficult for elderly person. On the other hand, from Fig.9 (b), standing up motion by elderly person requires smaller traction of knee joint and it is easy to elderly person only in this point.




(a) With Kamiya scheme (b) Elderly Person

Fig. 9 Traction Output

Table 2 Traction Output

| | | Pelvis/Trunk | Knee | Ankle |
|---|---|---|---|---|
| Case 1 | Max(Nm/kg) | 0.43 | 0.59 | 0.25 |
| | Output(Ws) | 26.0 | 39.3 | 20.6 |
| Case 2 | Max(Nm/kg) | 0.44 | 0.53 | 0.33 |
| | Output(Ws) | 30.0 | 43.2 | 28.3 |

From these results, for realizing the standing up motion with Kamiya scheme, the following conditions are required.

- ZMP should move from heel to foot ahead inclining trunk to forward direction during lifting up from chair.
- ZMP should locate on the center of foot for stability of the body after lifting up from chair.
- Force assistance is required during from 25 to 50[%] of movement pattern on knee joint.

## III. FORCE CONTROL

*A. Force Assistance during Standing up*

In this section, we discuss the force assistance scheme for realizing the standing up motion with Kamiya scheme. Our assistance system consists of support bar with two degrees of freedom and the bed system which can move up and down as shown in Fig.1.

The support bar can move up and down, forward and backward direction, thus, the bar is suitable to maintaining stable posture of the patient during standing up. However, we assume the patient sits down on the bed and grip the support bar with his hand. Therefore, the support bar should not assist him with strong force, because it is difficult to grip the bar if the assistance force is too strong comparing with his remaining physical strength of the hand.

On the other hand, the bed system can support the patient's body weight directly, thus, the bed can assist with stronger force. However, the bed system moves only up and down, and it is not suitable to assist the patient for maintain stable posture.

Considering with the characteristic of the support bar and the bed system, we design the force control system in the following policies.

- The support bar assists the patients for maintaining stable posture with small force during standing up.
- The bed system assists the patients directly with enough force for reducing the load of knee.

*B. Force control of bed system*

In general, we can divide the standing up motion into four phases. [16] In first phase, the patient still sits and inclines his trunk to forward direction. In second phase, he lifts off from the chair and in third phase, lifts the body. In fourth phase, he extends knee completely and ends the standing up motion. On the other hand, from the results of section 3, the force assistance is required during lifting up the trunk for reducing knee joint and in other period, it is required to maintain the stability of the body. Therefore, we assume the required assistance force is different in each phase as shown in Table 3.

Table 3 Four phases of standing up motion

| Phase | Priority | Action |
|---|---|---|
| 1:Flexion Momentum | Stability | Sitting |
| 2:Momentum Transfer | Stability | Lift-off |
| 3:Extension | Traction | Max Dorsiflexion |
| 4:Stabilization | Stability | End Hip Extension |

For realizing the required assistance force, in phase 1,2 and 3, the position control is suitable and in phase 3, the force control is suitable. Therefore, we propose the new control scheme which combines the damping control and position control in (4). The dumping control is suitable for the control of the objects with contact. The coordination and parameters are shown in Fig.10.

$$F_y^{bd} = \dot{y}_{bd}^{ref}(\hat{s}) - B(F - F_0) - K\left(y_{bd} - y_{bd}^{ref}\right) \quad (4)$$

where $\dot{y}_{bd}^{ref}$ is the velocity of control reference based on the movement pattern $\hat{s}$ and $y_{bd}^{ref}$ is the position of control reference. $F$ is measurement value of force which applied to the bed and $F_0$ is assistance force when the patient sits on it. $B$ and $K(\geq 0)$ are coefficients.

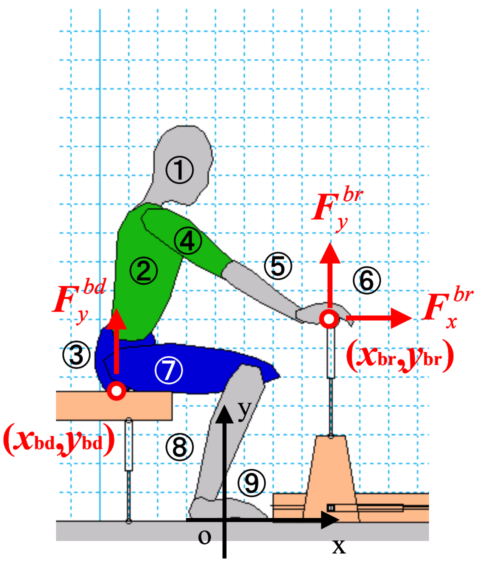



Fig. 10 Human model

Proposed control scheme has performance of both dumping control and position control by setting of appropriate coefficients. We set coefficients as shown in Table 4.

Table 4 Coefficients according to the priority

| Priority | *B* | *K* |
|---|---|---|
| Stability | Small | Large |
| Traction | Large | Small |

*C. Force control of the support bar*

In our system, the support bar assists the patients for maintaining stable posture during standing up motion. In section 2, ZMP is effective index of stability. Therefore, we proposed control scheme using ZMP as index in (5).

$$x_{zmp}^{ref} = \frac{\sum_{i=1}^{9} m_i(\ddot{y}_i + g)\bar{x}_i - \sum_{i=1}^{9} m_i \ddot{x}_i y_i - F_x^{br} y_{br} + F_y^{br} x_{br} + F_y^{bd} x_{br}}{\sum_{i=1}^{9} m_i(\ddot{y}_i + g) - \left(F_y^{br} + F_y^{bd}\right)} \quad (5)$$

where $x_{zmp}^{ref}$ is the ZMP position of control reference. $i(=1,\cdots,9)$ is identification number of the body segment, $\ddot{x}_i, \ddot{y}_i$ are acceleration of the center of gravity on the body segment in x-axis and y-axis, respectively. $m_i$ is mass of body segment and $g$ is gravitational acceleration. $x_{br}, y_{br}$ are the position of the support bar and $x_{bd}, y_{bd}$ are the position of the contact point between the bed and the patient's hip in x-axis and y-axis, respectively. $F_y^{bd}$ is traction output by bed system from (4).

Furthermore, output traction of the support bar $\left(F_x^{br}, F_y^{br}\right)$ should be minimum, thus, $\left(F_x^{br}, F_y^{br}\right)$ fulfills (6).

$$Minimize \quad F^{br} = \sqrt{F_x^{br^2} + F_y^{br^2}} \quad (6)$$

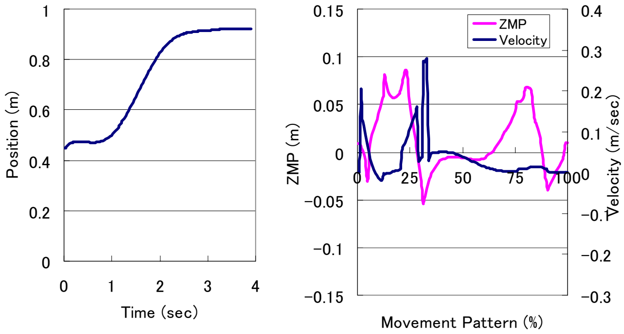
Using (5) and (6), we can derive the control values of the support bar $\left(F_x^{br}, F_y^{br}\right)$.

*D. Computer Simulation*

Here, we verify the performance of our control scheme by the computer simulation. In this experiment, the patient model stands up with Kamiya's motion and our force assistance system assists him using our proposed force control scheme. We compare the result by our proposed scheme with the result without the force assistance system. We use the control references as shown in Fig.11 which is derived from standing up motion with Kamiya scheme in section 2. We set coefficients in (4) experimentally as shown in Fig.12.

Fig.13 shows the simulation results. Fig.13(a) shows the traction output of pelvis and trunk joint during standing up and Fig.13 (b) and (c) show the traction output of knee and ankle joint, respectively. From 20 to 70[%] of movement pattern, our traction control reduces the load of each joint effectively. In Fig.13 (b), the maximum output of knee joints is reduced to 0.5[Nm/kg] by our proposed assistance control.

Table 5 shows the maximum output and output power of each joint. From these results, our proposed control scheme reduces maximum output to 0.5[Nm/kg] and maintains output power for standing up motion. Therefore, the patient is required to use his remaining physical strength and it is effective to prevent the decrease of physical strength.




(a) Position ( $y_{bd}^{ref}$ ) (b) Velocity ( $\dot{y}_{bd}^{ref}$ ) and ZMP ( $x_{zmp}^{ref}$ )

Fig. 11 Control References

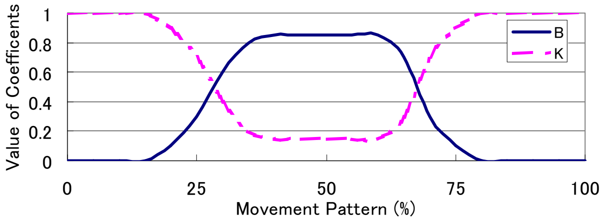
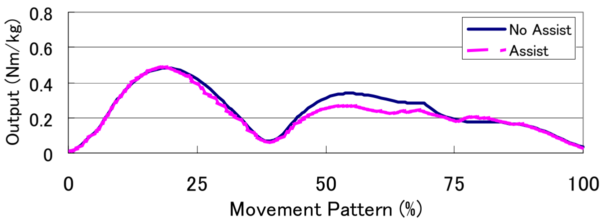
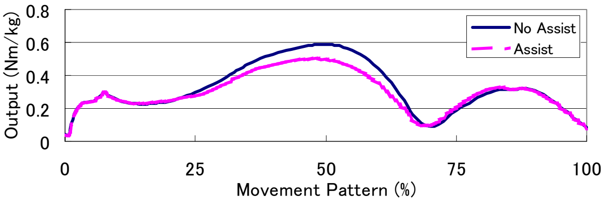


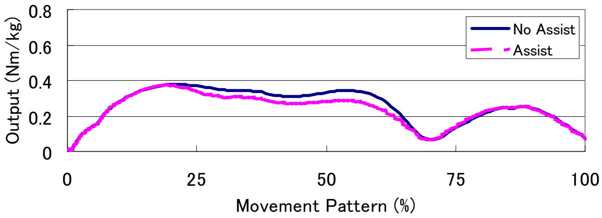

Fig. 12 Value of coefficients




(a) Pelvis/Trunk




(b) Knee




(c) Ankle

Fig. 13 Simulation Results

Table 5 Simulation Results

| | | Pelvis/Trunk | Knee | Ankle |
|---|---|---|---|---|
| No Assist | Max(Nm/kg) | 0.48 | 0.59 | 0.38 |
| | Output(Ws) | 29.0 | 39.3 | 31.0 |
| Assist | Max(Nm/kg) | 0.49 | 0.50 | 0.38 |
| | Output(Ws) | 26.9 | 36.3 | 28.8 |

## IV. Conclusion

In this paper, we develop the force control scheme for realizing the standing up assistance system which prevents the decreasing of physical strength by using the remaining physical strength of the patients maximum. We discuss the condition for realizing the effective standing up motion and design the force control scheme which fulfills this condition. Using our proposed force control, the load of knee reduces to 0.5[Nm/kg], which is maximum output of elderly person. The patient can stand up with fewer loads with our system. Furthermore, our assistance system requires the patient to use his own physical strength.

As our future works, we will develop the posture presumption method of a patient, because our developed system requires kinematic information of the patient.

This study is supported in part by Organization for Small and Medium Enterprises and Regional Innovation, Japan.

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