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STANDING ASSISTANCE WITH INSTINCTIVE ASSISTANCE MOVEMENT WHICH INSTRUCTS SUITABLE STANDING WAY

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This paper proposes a novel standing assistance scheme that guides a subject to adopt a suitable posture using intended movements. In many previous research, an assistive robot requires the patient to understand the standing reference beforehand and generally, the subject learns the standing motion used by the robot. However, for practical use, a patient should be able to use an assistive robot without special prior knowledge. Nursing specialists also guide their patients with an intended movement. For example, when they incline a patient's upper body before lifting it up, they guide the patient's body with a special moving pattern. Moving in this way is based on their experience and expertise and, in fact, the patient moves according to the motion intended by the nursing specialist. In this paper, we develop a standing assistance scheme that guides the patient to stand in the intended way. The effectiveness of the proposed method is verified by experiments with our prototype.

1. Introduction

Activities such as standing, walking, and sitting may be the most serious and important activities in the day-to-day lives of elderly people since they lack physical strength[1].[2] Therefore, developing a caregiving service robot capable of assisting the elderly when they stand, walk, and sit is important, and many such devices have been developed and reported in previous studies[3].[4]

In our previous studies, we developed an assistive robot that continuously aids patients with activities such as standing, walking, and sitting[5][6].[7] However, some patients failed to use our previous system to stand because they did not understand how they should move their body with our assistive robot (Fig. 1). These patients also could stand smoothly with the robot after we provided them detailed explanation on reference standing way with the robot.

On the other hand, nursing specialists guide patients with intended movements and do not explain standing way beforehand.[8] For example, when they incline a patient's upper body before lifting it up, they guide the patient's body with a special moving pattern. Moving in this way is based on their experience and expertise and, in fact, the patient moves according to the motion intended by the nursing specialists. Therefore, it is useful for a robotic assistant to provide such non-verbal instructions.

(a) prototype (b) suitable motion (c) unsuitable motion

Fig. 1. Standing motion using our latest prototype. (a) Suitable motion. The subject inclined his upper body and the center of gravity (COG) moved sufficiently in the forward direction. (b) Unsuitable motion. The subject did not incline his upper body enough and, as the result, his balance was bad.

Thus, this paper proposes a standing assistance scheme that guides the user to adopt the right body movements using the intended or reference movements. In our previous works, we investigated what characteristics of the reference motion show to the user the intention of the assistive robot.[9] Extending this findings, we design an assistance movement that teaches the reference body motion to the user, and we implement this motion in our prototype standing assistance robot.

2. Proposed Instinctive Assistance Motion

2.1. *Psychological Assessment*

In neurophysiology, previous research has analyzed voluntary human arm movements and demonstrated that they can be closely approximated by a minimum jerk trajectory model with a characteristic velocity profile.[10] In this paper, we used this model to design the assistive motion. In the minimum jerk trajectory model, human one-dimensional motion is expressed as the trajectories that minimize

$$C_j = \int_0^{t_f} \left(\frac{d^3 x\left(t\right)}{dt^3} \right)^2 dt \tag{1}$$

where t_f is the final time of the movement and $d^3 x\left(t\right)/dt^3$ is the differential of acceleration, called jerk. C_j is an extremum when $x\left(t\right)$ is the solution of the Euler–Poisson equation.

We assume that the boundary conditions are

$$\begin{array}{lll} x\left(t_0\right) = x_0, & \dot{x}\left(t_0\right) = \dot{x}_0, & \ddot{x}\left(t_0\right) = \ddot{x}_0, \\ x\left(t_0 + t_f\right) = x_f, & \dot{x}\left(t_0 + t_f\right) = 0, & \ddot{x}\left(t_0 + t_f\right) = 0. \end{array} \tag{2}$$

where x_f is the distance traveled and t_f is the time required for this motion. $x_0$is the start position andt_0 is time when the motion starts. Applying (2) to (1), $x\left(t\right)$ can be expressed

$$\begin{aligned} x\left(t\right) = x_0 + \left(x_f - x_0\right)\left(6\tau^5 - 15\tau^4 + 10\tau^3\right) \\ +\dot{x}_0\left(t - t_0\right)\left(-3\tau^4 + 8\tau^3 - 6\tau^2 + 1\right) \\ +\tfrac{\ddot{x}_0}{2}\left(t - t_0\right)^2\left(-\tau^3 + 3\tau^2 - 3\tau + 1\right), \end{aligned} \tag{3}$$

where

$$\tau = (t - t_0)/t_f \tag{4}$$

In (3) and (4), only two parameters (x_f and t_f) are required to derive the motion. Thus, we can design the following robot motions, which approximate typical human motion (Fig. 2). Each motions are same trajectories and same average velocity, however, these velocity profiles are different.

From our previous research,[9] humans tend to have different impression by time for the velocity to reach its peak value. The motion, which reaches its maximum velocity at the early period, tends to increase the aggressive impression and humans tend to follow the motion with this velocity profile. On the other hand, the motion, which reaches its maximum velocity at the late period, tends to increase the kind impression and human do not tend to follow the motion and tend to done their original intended motion.

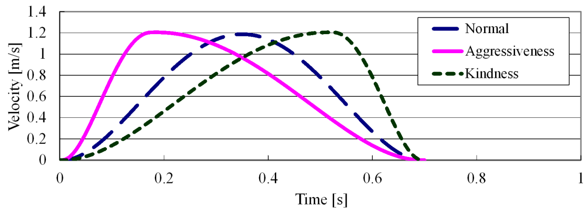


Fig. 2. Examples of velicuty profiles

2.2. *Standing Assistance Motion Design*

The standing motion recommended by nursing specialists can be divided into three phases.[8] In the first phase, the patient inclines his/her trunk forward. In the second phase, the patient lifts his/her buttocks up off the chair and lifts up his/her upper body. In the third phase, the patient extends his/her knee joint completely and ends the motion. To realize this standing motion, the following conditions should be fulfilled:

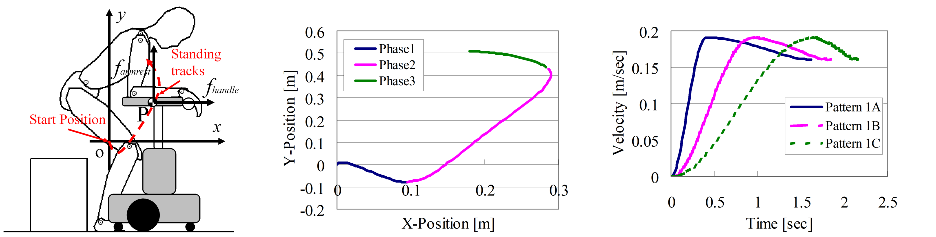
- In the first phase, the patient should incline his/her upper body forward so that his/her center of gravity (COG) is over his/her feet instead of his/her buttocks.
- In the second phase, the patient should smoothly change his/her direction of motion from forwards to upwards.

These conditions mean that the subject should undertake the required motion at each phase. Thus, the assistive robot should indicate to the user what motion is required at each phase during assistance. The intended motion of the robot should be designed based on the aggressiveness factor.

The standing motion recommended by nursing specialists[8] consists of three phases (Fig. 3(b)) and in each phase, the peak velocity occurs around 50% of the time for the whole movement pattern. Thus, we approximate the velocity profile of the assistance motion by the minimum jerk trajectory model as (3).

Considering the human impression as previous subsection, we shifted the relative time of the peak velocity. Fig. 3(c) shows the velocity profile for the first phase. For each movement pattern, the peak velocity was set to occur at 25% (pattern 1A), 50% (pattern 1B, which is the original one), and 75% (pattern 1C). Pattern 1A has a stronger aggressiveness factor and pattern 1C has a stronger kindness factor. Thus, we expect pattern 1A will guide the patient in the forward direction effectively in the first phase, which is useful for a patient who does not have an understanding of the standing assistance. On the other hand, we expect that pattern 1C will give a gentler impression to the patient, which is useful for patients who do not like robotic assistance.

The velocity profiles in Fig. 3(c) are based on the motion reference tracks in Fig. 3(b). In other words, Fig. 3(c) shows the velocity profiles of a point that moves along the position reference track shown in Fig. 3(b). Therefore, each standing assistance pattern has the same assistance position reference and the only differences are due to the velocity profile.



(a) coordination (b) recommended motion (c) velocity profile for the first phase

Fig. 3. Motion of our standing assistive robot. Its coordination is defined in (a). (b) Armrest motion of our robot, which realizes the standing motion recommended by nursing specialists. (c) Velocity profiles for the first phase. The difference between each pattern is due only to the velocity profile. Each pattern follows the same reference tracks shown in (b).

The velocity profiles for the second phase are listed in Table 1. The reference motion for each pattern is shown in Fig. 4. Fig. 4(a) shows the motion of the powered walker (in the X-direction) and Fig. 4(b) shows the motion of the standing assistance manipulator (in the Y-direction).

Table 1. Velocity profiles for the standing motion.

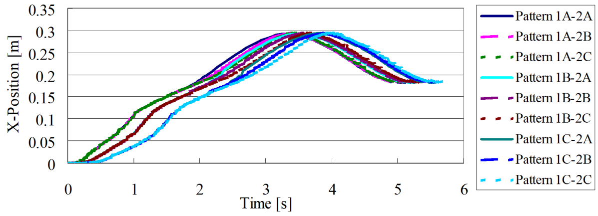
		Motion Pattern at Peak Velocity in 2nd Phase [%]		
		25%	50%	75%
Motion Pattern at Peak Velocity in 1st Phase [%]	25%	1A-2A	1A-2B	1A-2C
	50%	1B-2A	1B-2B	1B-2C
	75%	1C-2A	1C-2B	1C-2C

3. Standing Assistance Controller

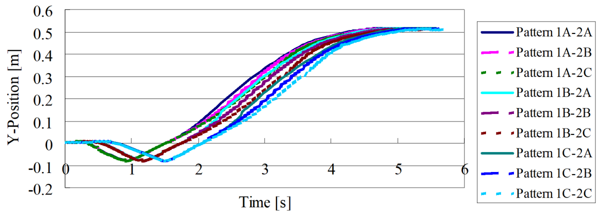
To instruct patients how to move his/ber body during standing up, our controller uses a combination of damping control and position control. Damping control can change the strength of assistive power, thus, it can determine how strong it applies assistance force to instruct the body movements to the reference pathway. Considering that the acceleration of the assistance motion guides the patient to stand in the intended way, damping control should be used when its motion accelerates.

However, damping control allows for an offset from the reference pathway of motion. By contrast, position control is useful for maintaining body posture. Considering that during the deceleration of the motion, the patient should converge on the reference posture. Thus, it is useful when its motion deaccelerates.

In our previous work[5,7] we proposed an assistance control algorithm based on damping control and position control. Using them, our robot succeeds to use the remaining physical strength of the patient during standing assistance. However, from the view point of how the robot guides the patient to the reference pathway, acceleration period and deceleration



(a) X-direction



(b) Y-direction

Fig. 4. Reference motion for each pattern. The difference between each pattern is due only to the velocity profile. Each pattern follows the same reference tracks. Therefore, the time required for each pattern is different, but the start and end positions are the same.

period have different role. Thus, each period requires different function, however, the previously reported algorithm did not consider it, so this paper extends this control algorithm as follows:

First, the robot has the reference position of P $\left(x_p^{ref}, y_p^{ref}\right)$ (Fig.3(a)) which is a motion reference point based on the standing motion recommended by nursing specialists (Fig.3(b)). Details regarding the generation of this reference point are given in our previous paper[5].[7]

$$
\begin{aligned}
&\mathbf{P} = \mathbf{v}_p^{ref}\left(\hat{s}\right),\\
&\mathbf{v}_p^{ref} = \begin{vmatrix} \dot{\mathbf{x}}_p^{ref} \\ \dot{\mathbf{y}}_p^{ref} \end{vmatrix}^T = \begin{vmatrix} \dot{x}_p^{ref}\left(0\right), \cdots, \dot{x}_p^{ref}\left(\hat{s}\right), \cdots, \dot{x}_p^{ref}\left(1\right) \\ \dot{y}_p^{ref}\left(0\right), \cdots, \dot{y}_p^{ref}\left(\hat{s}\right), \cdots, \dot{y}_p^{ref}\left(1\right) \end{vmatrix}^T
\end{aligned}
\tag{5}
$$

$$
\hat{s} = t/t_s \tag{6}
$$

In equation (6), t_s is the time required for completion of the standing-up operation and t is the present time.

Furthermore, our robot has control references for each actuator as detailed in (7), which realize the designed standing motion (5). $\dot{\mathbf{x}}_{rbt}^{ref}$ is the motion reference for a powered walker and $\dot{\mathbf{y}}_{rbt}^{ref}$ is for a standing assistance manipulator.

$$
\mathbf{v}_{rbt}^{ref} = \begin{vmatrix} \dot{\mathbf{x}}_{rbt}^{ref} \\ \dot{\mathbf{y}}_{rbt}^{ref} \end{vmatrix}^T = \begin{vmatrix} \dot{x}_{rbt}^{ref}\left(0\right), \cdots, \dot{x}_{rbt}^{ref}\left(\hat{s}\right), \cdots, \dot{x}_{rbt}^{ref}\left(1\right) \\ \dot{y}_{rbt}^{ref}\left(0\right), \cdots, \dot{y}_{rbt}^{ref}\left(\hat{s}\right), \cdots, \dot{y}_{rbt}^{ref}\left(1\right) \end{vmatrix}^T \tag{7}
$$

Our robot controls two actuators by (8).

$$
\begin{aligned}
&v_{rbt}^{upref} = \begin{vmatrix} \dot{x}_{rbt}^{upref} \\ \dot{y}_{rbt}^{upref} \end{vmatrix}^T\\
&= \begin{vmatrix} \dot{x}_{rbt}^{ref} - B\left(f_{handle} - f_{handle0}\right) - K\left(x_{rbt} - x_{rbt}^{ref}\right) \\ \dot{y}_{rbt}^{ref} - B\left(f_{armrest} - f_{armrest0}\right) - K\left(y_{rbt} - y_{rbt}^{ref}\right) \end{vmatrix}
\end{aligned}
\tag{8}
$$

where $\mathbf{v}_{rbt}^{upref}$ is the updated reference value that our robot actually uses for delivering standing assistance. (x_{rbt}, y_{rbt}) is the actual position of the powered walker and the standing assistance manipulator of our robot. f_{handle} and $f_{armrest}$ are the forces the patient applies to the assistance system when he or she stands as Fig. 3(a), and $f_{handle0}$ and $f_{armrest0}$ are them before he or she stands.

B and K in (8) are constants used to coordinate the ratio between the damping and position controls. When the robot accelerates, its controller selects damping control and it sets $B > K$. By contrast, when the robot deaccelerates, it selects position control and is sets $B < K$.

4. Experiments with prototype

4.1. *Experimental setup*

To verify the effectiveness of our proposed assistance scheme, we tested it as follows:

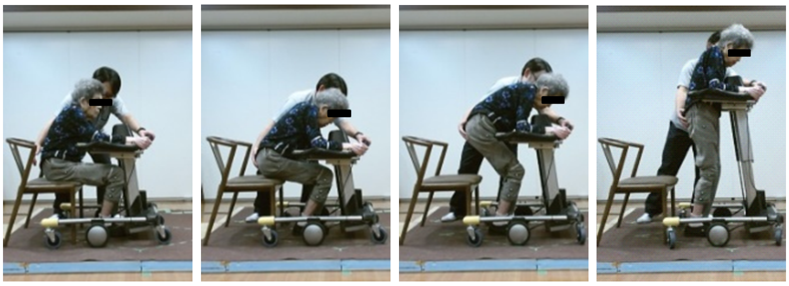
- The subjects were 12 elderly people whose care level is 1 or 2.
- The subjects stood up with the help of our assistive robot nine times. In each trial, a different standing motion pattern was used at random from Table 1. The subject did not know which pattern was used in each trial.
- The subjects were not told how our robot assisted them to stand. They had to judge how the assistive robot moved while using it and decide how to stand.
- To verify that the subject adopted the reference posture when standing, we measured the position of the COG of the subject's body.

4.2. *Experimental results*

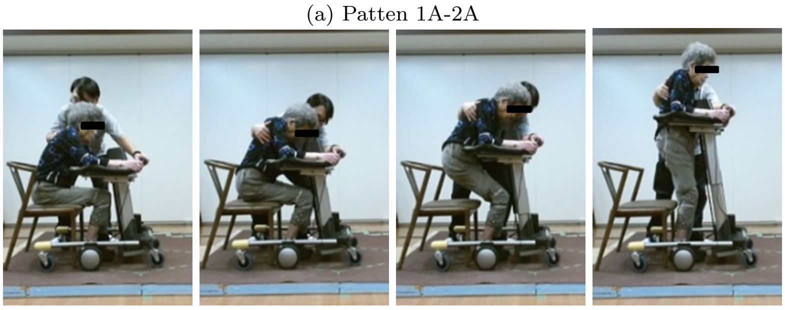
The subjects were successfully able to stand up with the assistance of our robot (Fig. 5(a)). In some cases, the subject adopted an unsuitable posture, especially for pattern 1C-2X (X is A, B, or C), as shown in Fig. 5(b).

Fig. 6 shows the position of the COG during standing. We observe the following:

- In Figs. 6(a), (b) and (c), the position of COG tends to move forward direction according to the reference path in the first phase. By contrast, in Figs. 6(g), (h) and (i), the position of COG does not move forward direction. From these results, in the first phase, the subjects succeed to incline their upper body by assistance motion with pattern 1A-2X (X is A, B, or C), which has aggressive motion at the first phase. On the other hand, using assistance motion with pattern 1C-2X, the subjects failed to incline their upper body which has kind motion at the first phase. In the first phase, the subject should incline his/her upper body and should move position of COG from his/her buttocks to his/her feet. Therefore, proposed assistance motion with an aggressive factor is better at guiding the subjects to the reference posture at first phase on standing motion.
- In Figs. 6(a), (d) and (g), the position of COG tends to lift up according to the reference path in the second phase. Furthermore, in Fig. 6(b), its movement has same tendency. By contrast, in Figs. 6(c), (f) and (i), the position of COG lifts up, however, its position is shifted to the backward direction.
  From these results, in the second phase, the subjects succeed to lift up their trunk sufficiently to achieve the final reference position by assistance motion with pattern 1X-2A (X is A, B, or C). With pattern 1X-2B, the subjects also succeed to stand up most of the time. However, if the body inclination was not enough in phase 1, sometimes the lifting movement failed as Fig. 6(g).



(a) Patten 1A-2A



(b) Pattern 1C-2B

Fig. 5. Standing motion. (a) Suitable motion. (b) Unsuitable motion. In this case, the subject failed to incline her upper body forward so that her COG is over her feet instead of her buttocks in the first phase. The therapists stands near the subject for safety reason and he does not assist the subject during assistance motion.

On the other hand, with pattern 1X-2C, the subjects do not lift up their trunk sufficiently to achieve the final reference position. In many cases, even if its height is acceptable, however, its position is too forward or backward.

In the second phase, the subject should lift up his/her upper body to the final reference position, and should maintain his/her body balance on this position. Lifting motion is easy to understand intuitively, thus, the subject simply can lift up his/her upper body without proposed motion. However, proposed assistance motion with an aggressive factor is better to achieve final reference position at the second phase on standing motion.

From these results, our robot can effectively provide non-verbal cues during the standing motion using the proposed aggressive assistance motion.

5. Conclusion

This paper investigates how cues can be added to the motion of a standing assistance scheme. Our prototype successfully guided our users to adopt a suitable standing posture. The motion proposed for standing assistance is based on the aggressiveness factor.

Acknowledgments

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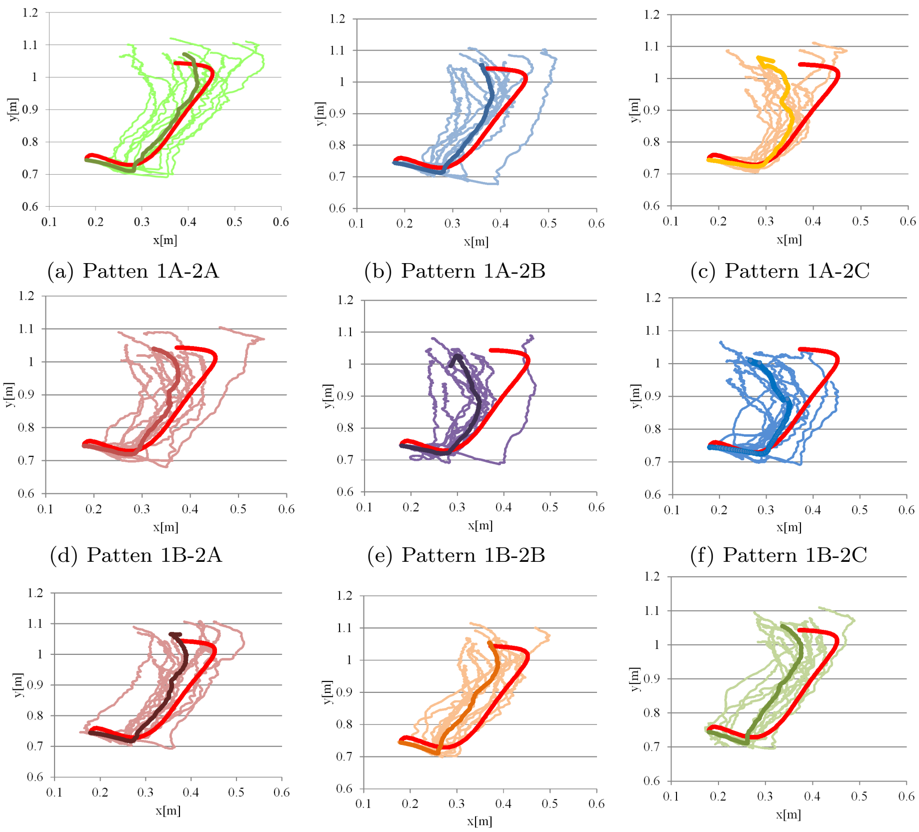
References

1. N. B. Alexander, A. B. Schultz and D. N. Warwick, *J. of Geometry: MEDICAL SCIENCES* **46**, M91 (1991).



(a) Patten 1A-2A (b) Pattern 1A-2B (c) Pattern 1A-2C

(d) Patten 1B-2A (e) Pattern 1B-2B (f) Pattern 1B-2C

(g) Patten 1C-2A (h) Pattern 1C-2B (i) Pattern 1C-2C

Fig. 6. Position of the COG during the standing motion. The bold lines show the average and the thin lines show the motion of each subject. The bold red line shows the position of the COG for the reference body motion.

2. M. A. Hughes and M. L. Schenkman, *J. of Rehabilitation Research and Development* **133**, 409 (1996).
3. K. Nagai, I. Nakanishi and H. Hanabusa, Assistance of self-transfer of patients using a power-assisting device, in *Proc. IEEE/RAS-EMBS Int. Conf. on Robotics and Automation (ICRA'03)*, (Taipei, Taiwan, 2003).
4. A. Funakubo, H. Tanishiro and Y. Fukui, *J. of the Society of Instrument and Control Engineers* **40**, 391 (2001).
5. D. Chugo, S. Muramatsu, S. Yokota and H. Hashimoto, A standing assistance for both voluntary movement and postural adjustment, in *Proc. Int. Conf. on Climbing and Walking Robots (CLAWAR'16)*, (London, UK, 2016).
6. S. Kawazoe, D. Chugo, S. Muramatsu, S. Yokota, H. Hashimoto, T. Katayama, Y. Mizuta and A. Koujina, Pattern based standing assistance for a low level of care, in *Proc. Int. Conf. on Climbing and Walking Robots (CLAWAR'17)*, (Porto, Portugal, 2017).
7. M. Yokota, S. Kawazoe, D. Chugo, S. Muramatsu, S. Yokota and H. Hashimoto, Standing assistance that considers user posture tolerance, in *Proc. Int. Conf. on Climbing and Walking Robots (CLAWAR'18)*, (Panama, 2018).
8. K. Kamiya, Development and evaluation of life support technology in nursing, in *Proc. 7th RACE Symp., Research into Intelligent Artifacts for the Generalization of Engineering*, (Tokyo, Japan, 2005).
9. D. Chugo, S. Aburatani, T. Masushige, S. Muramatsu, S. Yokota and H. Hashimoto, A hand movement which shows the intention of a robotic guide for safe walking, in *Proc. 24th Int. Symp. on Industrial Electronics (ISIE'15)*, (Guildford, UK, 2015).
10. T. Flash and N. Hogan, *J. of Neurosicence* **5**, 1688 (1985).