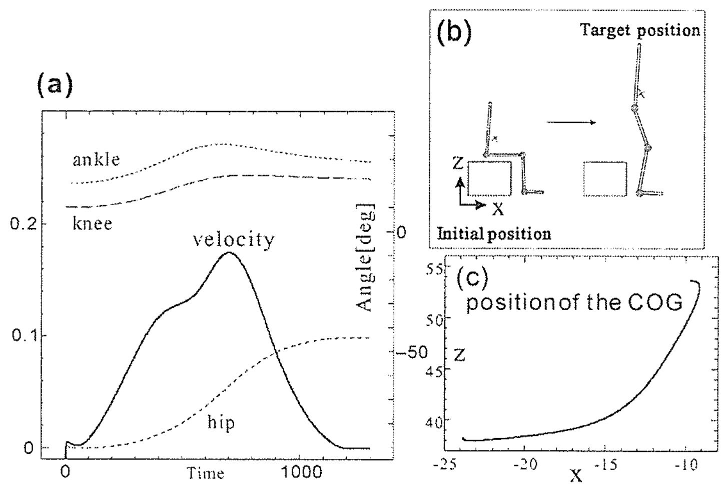


Figure 10. Standing-up movement of the four-link model. (a) Velocity transition of the COG position. (b) Initial and target states. (c) COG trajectory path from the side of the movement.

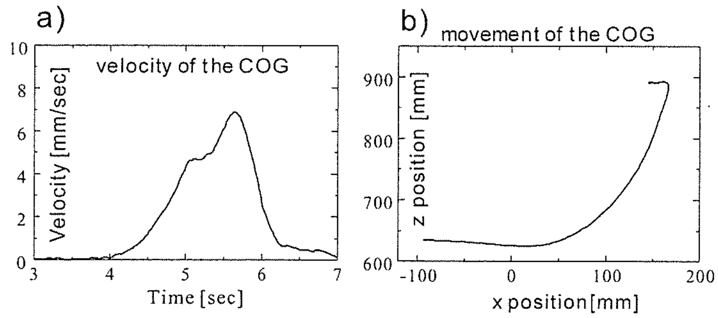


Figure 11. Optical-type motion-captured standing-up movement of a human. (a) Speed profile distribution of the COG position. (b) COG trajectory path from the side of the movement.

initial COG position in the seated state and the target position at the standing state. The reference position $\vec{x}_r$ is the midpoint between the initial and the target positions.

The speed distribution of the COG has basically one peak, and a smooth start and a convergence is seen in the speed profile curve. The COG trajectory path (from the side) is shown in Fig. 10c. Although the reference point $\vec{x}_r$ indicates the midpoint between the initial and the target points, the COG trajectory shows a slight drop due to the weight of the body and thereafter transits to the standing-up movement. These features suggest that the proposed method can handle redundant systems and can realize stable multi-link system movement. Figure 11 shows the speed profile distribution and the trajectory path of the COG movement of a human being standing-up, in which an optical motion capture system (VICON370,166 frames/s) is used. The speed profile pattern and the trajectory transition are similar.

The following experiment compares the slow-speed standing-up movement obtained by the four-link model and a human being. The simulation result of the

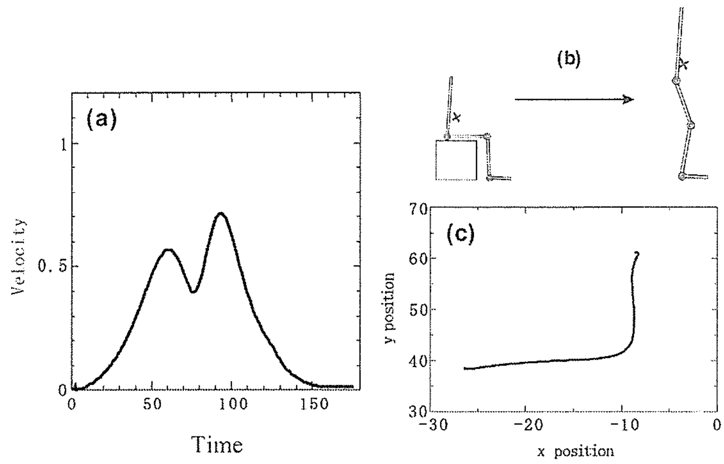


Figure 12. Slow-speed standing-up movement from a chair for the four-link model. (a) Speed transition of the COG. (b) Initial and the target states. (c) COG trajectory path from the side of the movement.

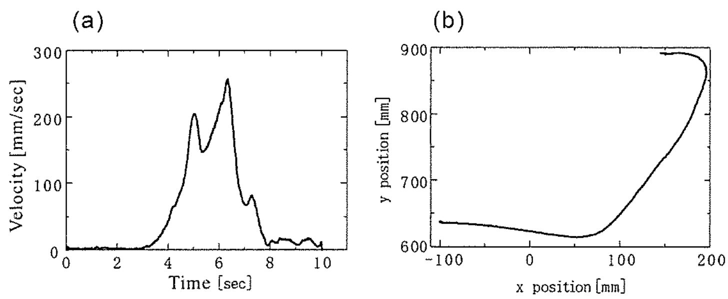


Figure 13. Motion-captured human slow-speed standing-up movement. (a) Velocity transition of the COG. (b) COG trajectory path from the side of the movement.

four-link model is shown in Fig. 12 and the human standing-up movement is shown in Fig. 13. In this experiment, the cost function parameter μ is taken as 2.0 rather than 1.0 (normal speed standing-up movement). Both movement features have two-peak speed distributions and represent a movement control strategy in which the control system first moves the COG to the support polygon and then pulls the COG up in the next phase. One- and two-peak speed profiles are found in the case of normal-speed and slow-speed standing-up movements, respectively. The reason for this is thought to be that 'the reaction' that pushes the body in the front is used for the movement [23], and in the case of normal-speed standing-up movement, when a change in the ground reaction force is observed, a rotation movement around the COG is caused by the tension applied to the floor and this rotation movement supports the standing-up movement.

Several studies examining standing-up movement have been reported in the rehabilitation field [23, 24]. The standing-up movement depends on the control strategy used to move the COG position to the top of the foot and the COG transition process using the reaction force when the control strategy bends the body corresponds to the normal-speed standing-up movement. This difference is basically the difference between 'static standing-up' and 'dynamic standing-up', and these features can be realized by the proposed method using the cost function parameter μ. The parameter μ is a weight parameter that indicates how the acceleration of the end-effector $\vec{a}$ corresponds to the speed profile control order $\vec{f}$.

For example, if μ is large, then the acceleration $\vec{a}$ of the end-effector will be relatively small compared to the control order $\vec{f}$. This situation means that practically realized acceleration of the end-effector is small for the control order of the speed control strategy and priority is given to the system dynamics compared to the control order. This indicates that the standing-up movement is realized without giving priority to the control order for the case in which $\mu = 2.0$, compared to that in which $\mu = 1.0$.

6. MATHEMATICAL ANALYSIS OF THE TRAJECTORY PLANNING CONTROLLER

The proposed trajectory planning controller is described as:

$$m\frac{\mathrm{d}^2\vec{x}}{\mathrm{d}t} = \alpha\left\|\frac{\mathrm{d}\vec{x}}{\mathrm{d}t}\right\| \cdot (\vec{x}_\mathrm{r} - \vec{x}) + \beta(\vec{x}_\mathrm{f} - \vec{x}). \tag{12}$$

Since the second term is a simple proportional term, we do not account for this term in the present analysis, thus clarifying the role of the first term.

When the speed distribution is assumed to be defined as follows:

$$\dot{\vec{x}} = \alpha(\vec{x} - \vec{x}_\mathrm{i}) \cdot (\vec{x}_\mathrm{f} - \vec{x}), \tag{13}$$

the time differential of (13) is derived as:

$$\ddot{\vec{x}} = \alpha\dot{\vec{x}}(\vec{x}_\mathrm{f} - \vec{x}) - \alpha(\vec{x} - \vec{x}_\mathrm{i})\dot{\vec{x}} = \alpha\dot{\vec{x}}(\vec{x}_\mathrm{i} + \vec{x}_\mathrm{f} - 2\vec{x}). \tag{14}$$

By the definition of $\vec{x}_\mathrm{r} = \frac{1}{2}(\vec{x}_\mathrm{i} + \vec{x}_\mathrm{f})$, the shape of the equation structure becomes similar to that of (12), with the exception of the coefficient. In other words, (12) is used to obtain the speed distribution in the form of (13).

Here, if the speed distribution is of the form shown in (13), we can calculate the trajectory distribution by integrating (13):

$$\frac{1}{\vec{x}_\mathrm{f} - \vec{x}_\mathrm{i}}\int\left[\frac{1}{\vec{x}} + \frac{1}{\vec{x}_\mathrm{f} - \vec{x}}\right]\mathrm{d}x = \frac{1}{\vec{x}_\mathrm{f} - \vec{x}_\mathrm{i}}\left[\ln(\vec{x}) - \ln(\vec{x}_\mathrm{f} - \vec{x})\right]_{\vec{x}_\mathrm{i}}^{\vec{x}_\mathrm{f}} = K\int_{t=0}^{t}\mathrm{d}t = Kt, \tag{15}$$

where K is a constant and a very small constant Δx is introduced because (15) cannot be integrated:

$$\frac{1}{\vec{x}_{\mathrm{f}} - \vec{x}_{\mathrm{i}}}\left[\ln(\vec{x}) - \ln(\vec{x}_{\mathrm{f}} - \vec{x})\right]_{\vec{x}_{\mathrm{i}}+\Delta x}^{\vec{x}_{\mathrm{f}}} = Kt. \tag{16}$$

That is, we have:

$$\frac{\vec{x} - \vec{x}_{\mathrm{i}}}{\vec{x}_{\mathrm{f}} - \vec{x}} = \exp K\left(\vec{x}_{\mathrm{f}} - \vec{x}_{\mathrm{i}}\right)t \cdot \frac{\Delta x}{\vec{x}_{\mathrm{f}} - \vec{x}_{\mathrm{i}}}. \tag{17}$$

By expansion about $\vec{x}$, we obtain:

$$\vec{x} = \frac{\Delta x \exp K(\vec{x}_{\mathrm{f}} - \vec{x}_{\mathrm{i}})t + \vec{x}_{\mathrm{i}}(\vec{x}_{\mathrm{f}} - \vec{x}_{\mathrm{i}})}{\vec{x}_{\mathrm{f}} - \vec{x}_{s} + \Delta x}, \tag{18}$$

which shows an analytical solution. Since Δx is a very small constant, the limit value is checked:

$$\begin{cases} t \mapsto 0 & \dfrac{\Delta x \cdot \vec{x}_{\mathrm{f}} + \vec{x}_{\mathrm{i}}(\vec{x}_{\mathrm{f}} - \vec{x}_{\mathrm{i}})}{\vec{x}_{\mathrm{f}} - \vec{x}_{\mathrm{i}} + \Delta x} \cong \vec{x}_{\mathrm{i}} \\ t \mapsto \infty & \dfrac{\Delta x \vec{x}_{\mathrm{f}}}{\Delta x} \cong \vec{x}_{\mathrm{f}}, \end{cases} \tag{19}$$

which means that $\vec{x}$ is in $\vec{x}_{\mathrm{i}}$ at $t = 0$ and reaches $\vec{x}_{\mathrm{f}}$ in time $t \mapsto \infty$. In addition, when the control term is of the shape of (12), by adding the term β, the stable equilibrium point of the system is only the point of $\vec{x}_{\mathrm{f}}$ and this system causes a reaching movement to the final position $\vec{x}_{\mathrm{f}}$.

We compared the proposed controller with the principle of minimum torque change (MTC) proposed by Uno *et al.* [16] from the viewpoint of ideal trajectory planning controller. The Lagrangian of 1D reaching movement under the condition of the MTC principle with friction is described as:

$$L = \frac{1}{2}\dot{f}^2 - \lambda(m\ddot{x} + k\dot{x} - f), \tag{20}$$

where f is force, $\ddot{x}$ is acceleration, $\dot{x}$ is speed, k is friction and λ is the Lagrange multiplier. By applying the principle of variation, we obtain the following set of equations:

$$\begin{cases} m\ddot{x} = -k\dot{x} + f \\ \ddot{f} = \lambda \\ \dot{\lambda} = -\dfrac{k}{m}\lambda. \end{cases} \tag{21}$$

Since $\lambda = A\exp^{-\frac{k}{m}t}$, f is given in general form as:

$$f = C + Bt + A\exp^{-\frac{k}{m}t}, \tag{22}$$

where A, B and C are constants. Here, the effect of $A\exp^{-\frac{k}{m}t}$ is thought to correspond to the friction effect and the basic structure of the MTC control can be rewritten as follows:

$$m\ddot{x} = C + Bt. \tag{23}$$

Figure 14 shows an example of MTC control under the condtion of $C = 5$, $B = -1$ and $t_f = 10$. From (23), the velocity profile is $\dot{x} = (1/2)t(10 - t)$ and the realized position distribution is close to a sigmoidal function; however, the velocity profile was not bell-shaped. Since the general case of multi-link MTC control is affected by both internal and external dynamics or disturbances, the realized speed profile is bell-shaped. On the other hand, the proposed method has a position-dependent speed profile (13) and the dependencies of the velocity and position profile on time of the MTC are thought to be the primary difference.

Concerning the stability of the controller, letting the dispersion of the external disturbances of the system be σ, we have:

$$\sigma < \pi \cdot \gamma, \tag{24}$$

where γ is the constant of (2). This is a condition of the stability against external force disturbances $\vec{f} \longmapsto \vec{f} + \vec{e}$. The stability analysis was performed using a red noise analysis and the second fluctuation-dissipation theorem. Here, we defined the noise dispersion of $\vec{e}$ as σ (detailed proofs are not shown). In the proposed method, the parameter α determines the reaching movement speed, as described in Section 4, and β acts only to supply a small initial velocity and to hold the particle at the final position, and μ is related to the dynamics of the reaching movement, as described in Section 5. In addition, the external disturbances are represented by the γ term.

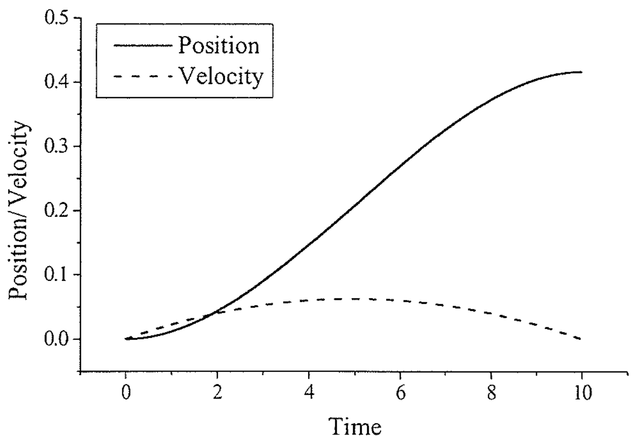


Figure 14. One-dimensional reaching movement control of minimum torque change under the condition of $t_f = 10$. The graph shows the position and velocity distribution when $f(t) = 5 - t$.

7. CONCLUSIONS

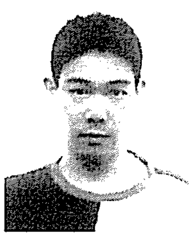
In the present paper, we propose a new control method of a multi-link arm system that was inspired by experimental results of reaching movement control in a macaque or human. In many cases, the planning and the force deciding process of previously proposed multi-link movement control methods use different algorithms and the entire multi-link dynamics cannot be managed. The proposed method unifies the trajectory planning and realization processes by exchanging the acceleration feedback information of the end-effector between these processes and the proposed method can manage external disturbances by converting the accumulation error of the trajectory realization process to the trajectory planning controller. Using this mechanism, we can determine each of the joint torques while performing the trajectory planning process and considering the dynamics of the system. The proposed method is an easy way of treating the redundant problems of multi-link system control and shows that some of the movement features of the reaching movement control are the same as those of biological systems, such as human standing-up movement.

REFERENCES

1. H. Kawamoto, S. Lee, S. Kanbe and Y. Sankai, Power assist method for hal-3 using emg-based feedback controller, in: *Proc. IEEE Int. SMC Conf.*, Washington, DC, pp. 1648–1653 (2003).
2. A. Katsnelson, Current approachs to the study of movement control, *PLoS Biol.* **1**, e50 (2003).
3. R. Volpe and P. Khosla, Computational considerations in the implementation of force control strategies, *J. Intell. Robotic Syst.* **9**, 121–148 (1994).
4. M. M. Williamson, Neural control of rhythmic arm movements, *Neural Networks* **11**, 1379–1394 (1998).
5. A. H. Fagg, N. Sitkoff, A. G. Barto and J. C. Houk, Cerebellar learning for control of a two-link arm in muscle space, in: *Proc. IEEE Conf. on Robotics and Automation*, Alburquerque, NM, pp. 2638–2644 (1997).
6. A. Hauck, M. Sorg, Schenk and G. Frber, What can be learned from human reach-to-grasp movements for the design of robotic hand-eye systems? in: *Proc. IEEE Int. Conf. on Robotics and Automation*, Detroit, MI, pp. 2521–2526 (1999).
7. T. Kashima and Y. Isurugi, Trajectory formation based on physiological characteristics of skeletal muscles, *Biol. Cybernet.* **78**, 413–422 (1998).
8. A. P. Georgopoulos, J. J. Lalaska and J. T. Massey, Spatial trajectories and reaction times of aimed movements: effects of practive, uncertainty, and change in target location, *J. Neurophysiol.* **46**, 725–743 (1981).
9. P. Morasso, Spatial control of arm movements, *Exp. Brain Res.* **42**, 2732–2743 (1981).
10. N. A. Bernstein, *The Coordination and Regulation of Movements*. Pergamon Press, Oxford (1976).
11. D. Bullock and S. Grossberg, VITE and FLETE: neural modules for trajectory formation and tension control, in: *Volitional Action*, W. Hershberger (Ed.), pp. 253–297. Elsevier, Amsterdam (1989).
12. A. Berardelli, M. Hallet, J. C. Rothwell, R. Agostino, M. Manfredi, M. Thompson, P. D. Thompson and C. D. Marsden, Single-joint rapid arm movements in normal subjects and in patients with motor disorders, *Brain* **119**, 661–674 (1996).

13. M. D. M. T. D. Sanger, Equilibrium point control of a monkey arm simulator by a fast learning tree structured artificial neural network, *Biol. Cybernet.* **68**, 499–508 (1993).
14. T. Flash, The control of hand equilibrium trajectories in multi-joint arm movements, *Biol. Cybernet.* **57**, 257–274 (1987).
15. M. Kawato, Y. Maeda, Y. Uno and R. Suzuki, Trajectory formation of arm movement by cascade neural network model based on minimum torque change criterion, *Biol. Cybernet.* **62**, 275–288 (1999).
16. Y. Uno, M. Kawato and R. Suzuki, Formation and control of optimal trajectory in human multijoint arm movement: minimum-torque change model, *Biol. Cybernet.* **61**, 89–101 (1989).
17. W. Abend, E. Bizzi and P. Morasso, Human arm trajectory formation, *Brain* **105**, 331–348 (1982).
18. A. G. Feldman, Superposition of motor programs. I. Rhythmic foream movements in man, *J. Neurosci.* **5**, 81–90 (1980).
19. H. Hogan, Impedance control; an approach to manupulation, part I to III, *ASME J. DSMC* **107**, 1–24 (1985).
20. S. Ma, Local torque optimization of redundant manupularots in torque-based formulation, in: *Proc. IEEE Int. Conf. on Industrial Electronics Control and Instrumentation*, Bologna, Vol. 2, pp. 696–701 (1994).
21. T. Flash and N. Hogan, The coordination of arm muvements: an experimentally confirmed mathematical model, *J. Neurosci.* **5**, 1688–1703 (1985).
22. W. T. Dempster, Space requirements of the seated operator, *WADC Technical Report*. Wright Patterson Air Force Base, OH.
23. J. Wheeler, C. Woodward, L. Ucovich, J. Perry and J. M. Walker, Rising from a chair: influence of age and chair design, *Phys. Ther.* **65**, 22–26 (1985).
24. R. G. Burdett, R. Habasevich, J. Pisciotta and S. R. Simon, Biomechanical comparison of rising from two types of chairs, *Phys. Ther.* **65**, 1177–1183 (1985).

ABOUT THE AUTHORS



Hideki Toda belongs to the Doctoral Program of Systems and Information Engineering, Sankai Laboratory, University of Tsukuba, Tsukuba, Japan and the Multimodal Integration Research Group, Institute for Human Science and Biomedical Engineering, National Institute of Advanced Industrial Science and Technology.

Tatsu Kobayakawa belongs to the Multimodal Integration Research Group, Institute for Human Science and Biomedical Engineering, National Institute of Advanced Industrial Science and Technology.

Yoshiyuki Sankai received the PhD degree in Engineering from the University of Tsukuba, Japan, in 1987. He was named a JSPS Fellow, Research Associate and Associate Professor in the University of Tsukuba. He is a Visiting Professor at Baylor College of Medicine, USA, and an Ordinary Professor in the Institute of Systems and Engineering Mechanics, University of Tsukuba, Japan. His research interests include assistive exoskeletal robots, the next generation of artificial hearts and humanoids as related fields of cybernetics. He received the JSAO-Grant of the Japanese Society for Artificial Organs, and awards from the American Society for Artificial Organs, International Society for Artificial Organs and International Society for Rotary Blood Pump with his students. He is a Chair of the Japan Society of Embolus Detection and Treatment, Vice Chair of the International Journal of the Robotics Society of Japan, member of the Awards Committee of the Japan Society of Mechanical Engineers, and member of the Assessment Committee of the New Energy and Industrial Technology Development Organization, Japan.

人間の動作特性を考慮したロボットスーツＨＡＬによる立ち上がり動作支援に関する研究

○河本浩明*1*2，塚原淳*2，山海嘉之*2
*1 財団法人医療機器センター，*2 筑波大学大学院システム情報工学研究科

Study on Standing-Up Motion Support Using on Motion Property of Human for Robot Suit HAL

○Hiroaki KAWAMOTO*1*2, Atsushi Tsukahara*2 and Yoshiyuki SANKAI*2
*1 Japan Association for the Advancement of Medical Equipment
*2 Graduate School of Systems and information Engineering, University of Tsukuba

Abstract: We have developed Robot Suit HAL (Hybrid Assistive Limb) which enhances human physical function by using Cybernics technologies which is a new academic research field based on Cybernetics, Mechatronics, and Informatics. We propose Cybenic-robot control system to support motion depended on motion condition of robot suit wearer and apply this method to standing-up motion.

1. 緒言

我々は人間・機械・情報系の複合融合新領域サイバニクスの技術を駆使し，人間と機械が一体となって，人間の身体機能を増幅・拡張するロボットスーツＨＡＬを開発している[1]. 本研究では，ロボットスーツ装着者の動作状態に適応する自律的動作支援手法を提案する．本手法は人間の動作特性に基づいて，一連の運動を Phase として分離し，これを再合成する Phase Sequence 手法を利用し，人間の動作特性を反映した動作支援を実現させるものである．本報告では，立ち上がり動作に関して本手法を適用し，現時点の最新成果について述べる．

2. 立ち上がり動作支援方法

2.1 Phase Sequence 法[1]

人間的な動作を生成する Phase Sequence 法は主に３段階から構成されている（Fig.1）．１）歩行，立ち上がりといった一連の機能的な運動から生理情報，運動情報を獲得する．２）獲得した情報から，人間の運動特性に基づき，一連の運動を基本的な運動単位（Phase）に分離する．３）各 Phase に制御則を組み込み，再合成する．これによって，一連の人間的な運動を実現させる．

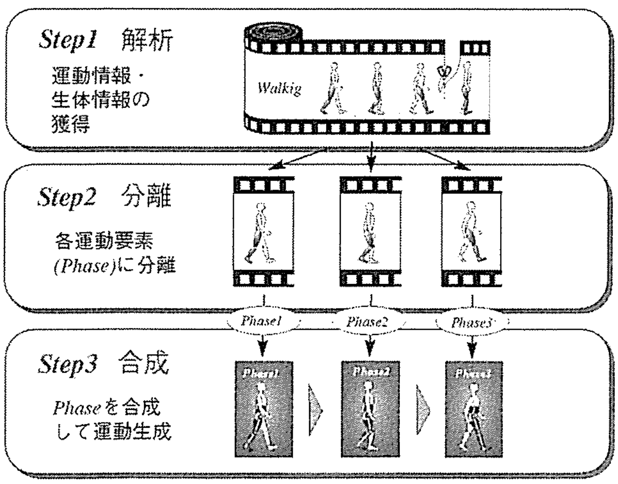


Fig.1 Phase Sequence method

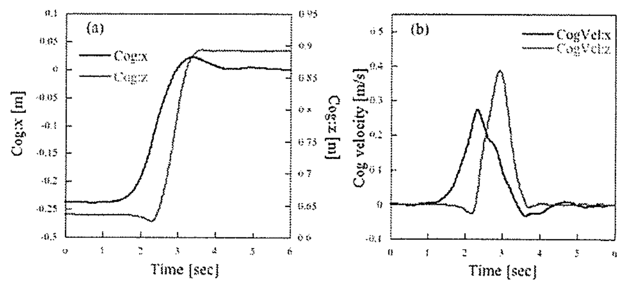


Fig.2 Motional analysis for Standing-up motion of normal person[2]. (a) Cog trajectory, (b) Cog velocity

2.2 動作解析および Phase 分解

まず，立ち上がり動作を Phase に分解するため，動作解析を行う[2]．身体重心に着目し，ごく普通の早さによる立ち上がり動作時の，座面を離れてから直立するまでの前後方向 (x, 前向き+) と上下方向 (z, 上向き+) の重心位置と速度を Fig. ２に示す．重心速度を見ていると，各方向とも始点から終点まで一連の釣り鐘（ベル）型になっていることがわかる．さらに，x 方向の速度が最大になったとき，z 方向の速度が生じ始めているのがわかる．

解析結果より，人間の立ち上がり動作は重心の前方移動と上方移動動作に分離すると，各動作はベル型の速度分布を有し，動作タイミングは前方移動から始まり，十分な速度を得

た後，上方移動が始まることがわかる．これは，前方方向のといった，身体特性を活かした立ち上がり動作といえる．

以上の考察より，立ち上がり動作の Phase を以下のように分離する．

Phase 1　：座位姿勢

Phase 2　：重心を前方へ移動

Phase 3　：重心を上方へ移動

Phase 4　：直立姿勢

2.2 Phase の動作計画

前節の解析結果より得られたベル型の速度分布は生物特有の運動である．特に人間やサルの腕の到達運動の際の腕の先端部分の速度分布では，ベル型の形状をとるという性質がよく知られている．立ち上がり動作においても，人間的な動作特性を身体重心の運動からみることができた．本研究では，人間的な動作特性に基づく動作支援方法として，ロボットスーツ装着者の身体重心がベル型速度分布に従う動作支援方法を提案する．

まず，前後方向および上下方向に関する重心の運動をロボットスーツおよび装着者の全重量を重心位置に集中させた倒立振子モデルとして考える（Fig.3）．

$$m\ddot{x} = F_x \tag{1}$$

$$m\ddot{z} = -mg + F_z \tag{2}$$

ただし，mは中心質量，gは重力加速度である．ここで，身体重心の座位位置(x_s, z_s)から立位位置(x_f, z_f)とし，ベル型の速度分布を取る速度分布制御則を用いると，F_xとF_zは以下のように表される[3]．

$$F_x = \alpha_x \dot{x}(x_r - x) + \beta_x(x_f - x) \tag{3}$$

$$\frac{dF_z}{dt} = -\gamma(F_z - g - D) \tag{4}$$

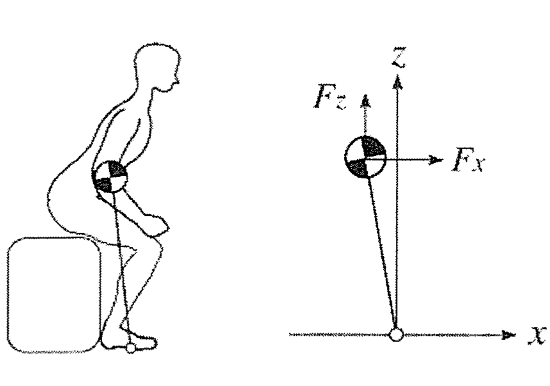


Fig. 3 Dynamics model of standing-up motion

$$D = \alpha_z \dot{z}(z_r - z) + \beta_z(z_f - z) \tag{5}$$

$$(x_r, z_r) = \{(x_s, z_s) + (x_f, z_f)\}/2 \tag{6}$$

ただし，α_i，β_i $(i = x, z)$，γはそれぞれ正の定数を表す．

各 *Phase* の制御および遷移に関しては，*Phase 1* から上半身の傾倒動作が開始すると，*Phase 2* に遷移し，F_xを生成する．$\dot{x}$が最大になった後，*Phase 3* に遷移させF_zを生成する．最後に直立姿勢に到達すると *Phase 4* に遷移させる．

3. 立ち上がりシミュレーション

以上説明した方法を用いて，身長 170[cm],体重 60[kg]の人間を想定し，立ち上がり支援動作のシミュレーションを実施した．各制御則のパラメータとして，$\alpha_x = 1200$，$\alpha_z = 0.5$，$\beta_x = 500$，$\beta_z = 50$，$\gamma = 80$ を用いた．身体重心の軌道および速度分布を Fig.4 に示す．Fig.2 の立ち上がり動作とほぼ同じ軌道および速度分布を実現することができた．

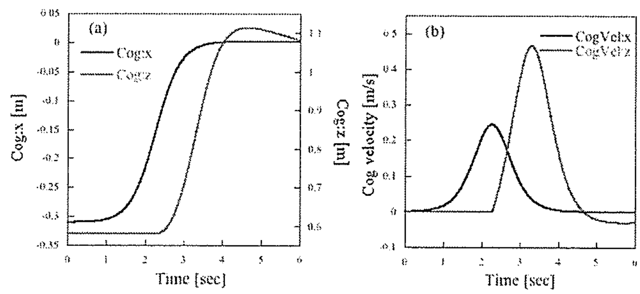


Fig.4 Simulation result of standing-up motion support
(a) Cog trajectory, (b) Cog velocity

4. 結言

本稿では人間の動作の特性を活かした動作支援方法として，身体重心がベル型速度分布をとる運動制御則を導入し，シミュレーションによりその有効性を確認した．今後は，身体重心の加速度に着目した評価関数によるトルクパターン生成法を組み込み，実機による立ち上がり動作実験に進む予定である．

参考文献

[1] H. Kawamoto and Y. Sankai, Power assist method based on Phase Sequence and muscle force condition for HAL, Advanced Robotics, vol.19, no.7, pp.717-734, 2005

[2] 江原義弘，山本澄子，ボディダイナミクス入門 立ち上がり動作の分析，医歯薬出版，2001

[3] Toda H., Kobayakawa T., Sankai, Y., A multi-link system control strategy based on biological reaching movement, Advanced Robotics, vol. 20, no. 6, pp. 661-679, 2006

Forbes 2006. 9. 4

Rise of the Cyborg

LIKE A LOT OF JAPANESE BOYS WHO GREW UP IN THE 1960S, YOSHIYUKI SANKAI SPENT HOURS in front of the TV set, engrossed by the heroics of Cyborg 009 and Astroboy, half-man, half-machine cyborgs. He wanted to make these fictional half-breeds a reality. Sankai, 48, is one of Japan's foremost experts in cybernetics, the science of merging man with machine. His work is soon to become a business, as Sankai begins selling a suit known as HAL, the Hybrid Assisted Limb. (He picked that acronym to echo the off-the-rails computer in *2001: A Space Odyssey*.) "My basic motivation is to develop devices to enhance and expand human ability," he says in an interview at his office at Tsukuba University, a research hub north of Tokyo.

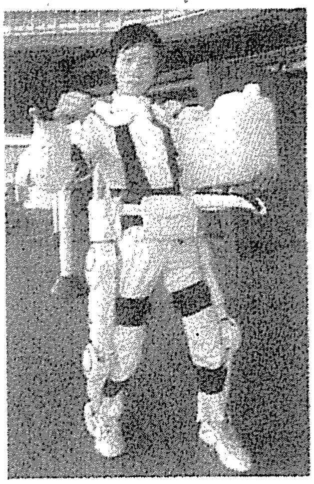
HAL turns its wearer, if only temporarily, into a cyborg, boosting strength and endurance: Your arms can lift an extra 88 pounds beyond what you can lift without it. Nurses can move patients from their beds with

CAROLINE PARSONS FOR FORBES

読売新聞 2006. 10. 29

ロボットスーツ実用化

筑波大開発、介護などに期待



量産化が決まったロボットスーツ

筑波大学が開発した、手足の力を増強するロボットスーツ「HAL」が、国内外で評判となり、実用化されることになった。来年には茨城県つくば市内に生産工場を開設し、量産体制に入る。

「HAL」は、装着した人が筋肉を動かす時に出る微弱な電気を感知、体の動きに合わせてモーターも動く。女性や非力な人でも70～80キロ・グラムの人や物体を抱えあげ、100キロ・グラム以上の荷物を背負うことができる。足の不自由な人の歩行補助やリハビリ、介護、工場労働、災害救助など幅広い応用が期待されている。

開発者の山海嘉之・同大教授によると、問い合わせが400件以上に達したため、量産化を決めた。

ビジネス化はベンチャー企業「サイバーダイン」（本社・つくば市）が担当。当面は年20体程度の生産体制を敷き、2008年には年間400～500体に生産ラインを拡大する。

値段は医療機関向けには約500万～700万円になるが、個人向けにはレンタル料（月7万円）と維持費だけに抑える予定だ。来月上旬、つくば市内の病院に実用化第1号の製品を納入する。

SIDELINES

“解体”され始めたロボット

二足歩行や高度な認知能力など**人間型ロボット**のために開発された技術が、個別に実用化され始めている。鉄腕アトム[▷⑦]のように高度に統合されたロボットの実現にはまだまだ時間がかかりそうだが、そこに至る前に早くもその“解体”が始まったようにも見える。

たとえば**ロボットスーツ**。日本では筑波大学、米国では**国防高等研究計画局**(**DARPA**)の依頼を受けたカリフォルニア大学バークレー校などで開発が進んでいる。筑波大では、研究室が主体となってベンチャー企業を設立し、事業化を目指している。当面の主な用途は足が不自由な人の歩行支援だ。

あるいは、**人工皮膚**[▷㉒]。東北大学では、ロボット用に開発された人工皮膚を指サック型にし、指につけて点字をなぞると読み上げてくれるシステムの開発を進めている。2006年5月現在で、1秒間に約20文字を90%程度の精度で識別できるという。点字の習得が困難な中途失明者にとって、朗報になる可能性がある。

もともと、人間型ロボットの開発は、人間の動作やコミュニケーションを機械的・電子的に再現することを目的に開発が進んできた。研究者にとっての入口は「人間の二足歩行の秘密を解明したい」「人間の認知の仕組みを知りたい」「子供時代に見た鉄腕アトムを実現したい」──など様々。だが全体とすれば、健康体の人間の身体(骨格、筋肉、神経系など)を模倣する技術の体系として発展してきたといえる。その結果、ロボットの各要素技術は互いに連携することを前提として開発されるようになった。このことが、欠損した身体機能の置き換えという次元を超えた、**障害補助器具**の開発を促しているともいえる。

Japan Times 2006. 12. 31

Shaping our future along with robots

By TOMOKO OTAKE
Staff writer

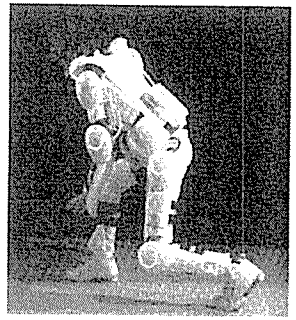
Yoshiyuki Sankai is a professor of engineering at Tsukuba University in Ibaraki Prefecture and a front-runner in the field of "cybernics," which combines robotics with a wide array of academic disciplines, including neurology, information technology, behavioral science and psychology. Now aged 48, he is most famous for developing HAL, a "robot suit" that moves with its wearer by detecting the subtle electrical changes in muscles as they move. HAL (no relation to the "killer" computer in Stanley Kubrick's famed movie, "2001: A Space Odyssey"), which stands for "hybrid assistive limb," can help wearers to perform tasks they would not normally be capable of, such as lifting 180 kg on a leg-press machine, or assist those with disabilities in numerous ways.

What can we expect in robotics in 2007?

So far, some prototypes have been released, following a turning point in robotics in 2005 when the government, led by the Ministry of Economy, Trade and Industry, decided we should move on from the exploration of basic technologies and start making prototypes, and also standardize our technologies, both hardware and software, to foster the development of robots. In 2007, several organizations will start test-marketing robot products.

What kind of products will these be?

Roughly three types. The first type is pet robots, which have already been test-marketed, and makers are pondering commercial strategies for next year. Also, there are the so-called hobby robots, which are 30- to 50-cm long and could replace radio-controlled cars and machines. Then there are the "serious" robots for medical and rehabilitative applications. But the



interesting thing is, there will be some interaction between the technologies used in those different types, like complex robots getting the feedback from hobby robots, for example. And more fundamentally, robots and robotics will be defined clearly as being helpful in the context of the graying population.

What would you describe HAL as?

HAL is in the cyborg category, which is part human and part machine.

What do you think will happen to Japan's robotics in the mid-term?

I think by 2020, robots and robotic technologies will be fully integrated in our lives. In 2008 and 2009, the first waves of new technologies will arrive, which will make people feel like, "Wow! Is this happening already?" One example would be our HAL 5. I have created a venture company called Cyberdyne for the R&D, production management and quality control of HALs. We will have European bases, the first of which will probably be set up in the Netherlands early next year, and then in North America six months later. By the end of 2008, we will have made 400 to 500 units. They will be used in hospitals to help patients rehabilitate.

What other future developments do you have in mind?

Following our primary goal of serving medical and rehabilitative needs, our company will develop products to help with heavyweight factory or construction work. Also, our robots can be used in the field of entertainment.

For instance, by having HAL wearers also wear head-mounted displays, they can watch somebody walking through deep snow and, by having HAL put pressure on their legs, they can feel the sensation themselves. Or we can create a situation where you might be watching a movie at home with a head-mounted display and a HAL suit on, then feel your right leg suddenly being harshly pulled just as Sadako (a creepy character in the horror movie "Ring") is grabbing someone's right leg in the film! That kind of experience would be possible.

In the mid- to long-term future, some experts say Japan's population will fall so much that robots and immigration will not compensate enough for the loss in output. What is your view on that?

In most manufacturing businesses, robots are already doing the work of humans. So Japan's economy is being supported by both people and robots in that field. From now on, intellectual property will be a bigger and bigger part of Japan's competitiveness, but with rights' infringements, which are rampant in the rest of Asia, it will be difficult to make intellectual property our strength.

An alternative approach for Japan would be to model itself on European examples of producing high-quality goods. In Germany, they sell very high-quality goods, including my chair, which costs ¥130,000! Switzerland has Roche, Nestle. . . . Many of these companies are not large in size, but they are world famous.

This is the approach I think Japanese companies should take if they want to survive. It was only a handful of people who started Sony and built it into a global name. Challengers are hard to get set up and survive, but if Japan can ensure freedom and create a support mechanism for such challengers — primarily motivated scientists and engineers — small-size, world-class businesses will compete well. China might equal or surpass Japan in overall GDP, but the survival scenario for Japan will be to have companies with high-tech, high-quality products run by a select few, and have those companies based here but with operations all over the world.

How do you foresee robotics in, say, 2050?

As I see it, mankind has given up on evolution by inventing and utilizing various technologies. The gap between technology and people has been big until now. But computers have become much easier to use, which means people and technology are getting closer. Suppose you have a grandma living far away in the countryside. I could give you a window

グッドデザイン賞イヤーブック 2007. 1. 30

Robot Suit

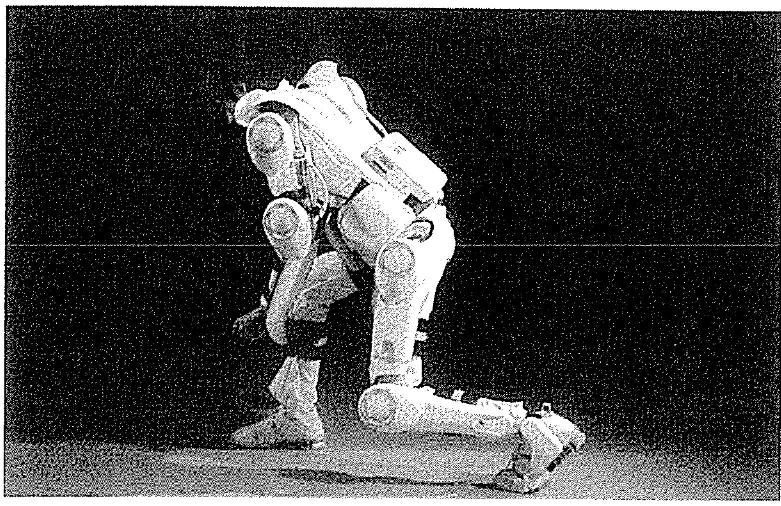
HAL-5

Ar CYBERDYNE Inc. + Elm Design Co., Ltd.
Yoshiyuki Sankai, President, CYBERDYNE Inc.
Dr [illegible] Manager, Elm Design Co., Ltd.
D Takahiro Kanke, Designer, Elm Design Co. [illegible]

The large number of applications from scientists nominating a variety of robots was a notable aspect of this year's screening. Among them, the HAL wearable robotic suit stood apart. The designers sought to affirm the suit's usefulness from a medical standpoint while toning down any hard, mechanical feeling as seen in previous concept robots. Here, it is clear how, through their design work, the designers strove to help physically disabled individuals scale their psychological barriers. Further research will probably be required before use at medical facilities, but HAL is certainly worth closer examination as a model design heralding a new direction in robotics, toward a synergy between humans and machines. The results of this research and design work also point to new possibilities in non-medical applications, as a robot for purposes of entertainment. [Manabu Akaike]

Japan Markt 2007. 3. 10

„Kleider“ machen Leute



Prof. Sankai, Univ. of Tsukuba / CYBERDYNE Inc.

▲ Roboteranzug HAL: Mehr Beweglichkeit dank neuer Technik

Eine völlig neue Bedeutung erhält dieser Satz, wenn man sich die neueste Erfindung von Wissenschaftlern der Tsukuba-Universität betrachtet. Denn dort hat man einen neuen Roboteranzug entwickelt, der trotz seines futuristischen Aussehens weniger modischen Ansprüchen genügen, sondern die Kraft und Beweglichkeit seines Trägers in hohem Maße verbessern soll. Zielgruppe sind vor allem bewegungseingeschränkte ältere Menschen, denen so ein selbstständigeres Leben ermöglicht werden kann. HAL (Hybrid Assistive Limb), wie der Name des Anzugs lautet, funktioniert dabei mit Sensoren, die auf der Haut angebracht sind. Registrieren diese die kurz vor einer Körperbewegung abgegebenen elektrischen Impulse des Gehirns, reagieren die entsprechenden Roboterkörperteile und führen die Bewegung selbstständig aus. Gehen und das Heben schwerer Gegenstände kann mit diesem Anzug also auch mit nur ganz geringem Kraftaufwand betrieben werden.

Die Firma Cyberdyne, ein von der Tsukuba-Universität gegründetes Unternehmen, und der Fertighaushersteller Daiwa House planen, den Anzug in Zukunft in Zusammenarbeit zu produzieren. HAL wird gerade in Pflegeeinrichtungen getestet und könnte ab 2008 schon an erste Pflege- oder Rehabilitationszentren verliehen oder verkauft werden. **JM**

The Japan Economic Review 2007. 3. 15

Wearable robots to come into use

Utilized in lifestyle support for the elderly and for heavy work at factories

Robot suits that will assist people in moving their legs and arms are soon to come into practical use. The suits are developed by Cyberdyne, a venture enterprise in Tsukuba City, Ibaraki Prefecture. Cyberdyne intends to launch mass-production of the robot suits with Daiwa House Industry, Co., Ltd as one of the partners. Some 400 suits will be produced annually from 2008 onwards to be used in various areas, such as healthcare, welfare and nursing, as well as for physical labor and heavy work. The product is scheduled to hit the market in 2008. It will be distributed on a rental basis. Toyota Motor Corporation is also advancing plans to utilize robot suits for heavy work at its factories.

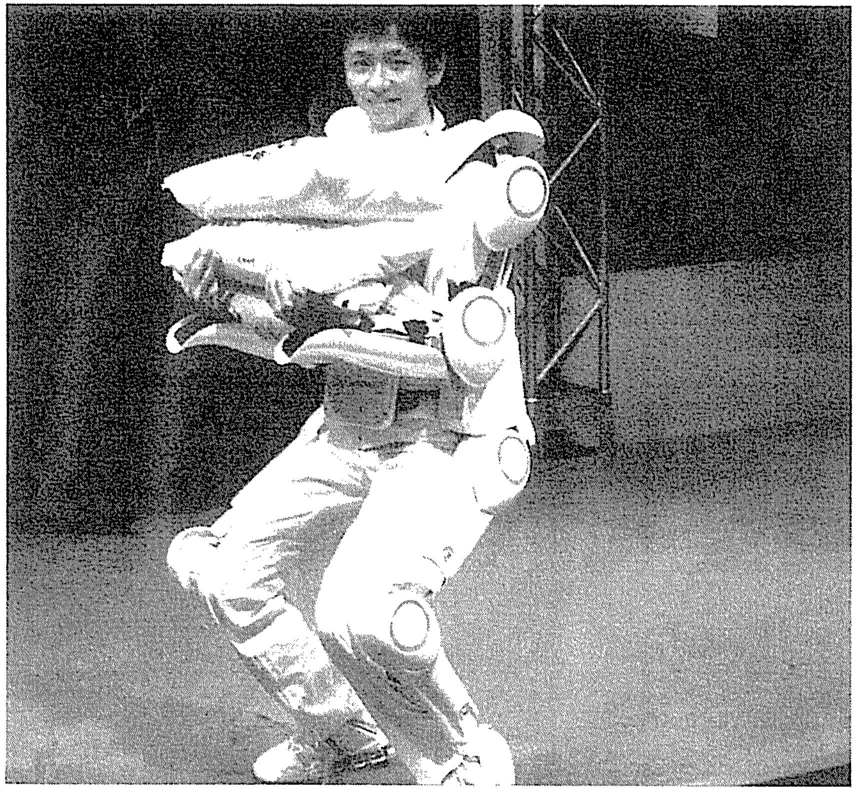
The robot suits developed by Cyberdyne are known as Hybrid Assistive Limb (HAL), and their function is to assist human movement. People set their muscles in motion through bioelectric signals generated by the brain and transmitted by the neurons. The robot suit operates by sensing electric signals generated by the brain via electrodes on the operator's skin and activating servo-motors attached at the joints of the limbs just a moment before the muscle-initiated movement.

This mechanism allows people who wear the suit to move easily, relieving the burden applied on the limbs and back. It also enables the operator to lift and carry a load of more than 20 kilograms with one hand.

By wearing the robot suit, elderly people who need nursing care will be able to perform a wide range of movements much more easily.

Another possible application of this technology that is being explored is its utilization by workers at factories for transporting heavy loads. Toyota too plans to develop robot suits that will replace the use of cranes in the transportation of engines and auto body components.

Japan is famous as the world's most advanced nation in terms of robot technologies. However, at present the most commonly-used robots are of the arm-type installed at factories to perform welding and coating. Wearable devices of the HAL-type that assist and strengthen human movement are fairly rare.



The robot suits developed by Cyberdyne. (By courtesy of Prof. San Kai, University of Tsukuba/Cyberdyne, Inc.)

Emergency assistance to Bolivia for torrential rain disaster

The Government of Japan has decided on February 7 to provide emergency relief

damage caused by the torrential rain, which is damaging infrastructure like roads al