Toward New Humanoid Applications: Wearable Device Evaluation Through Human Motion Reproduction

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Towards new humanoid applications: wearable device evaluation through human motion reproduction

Eiichi Yoshida, Ko Ayusawa, Yumeko Imamura, and Takayuki Tanaka

Abstract This chapter addresses a new application of humanoid robot for evaluation of wearable assistive devices. One of the issues for diffusion of assistive devices that have been developed recently is its objective and qualitative evaluation to validate its assistive effects. Human subject experiments that have frequently been used have several drawbacks such as heavy ethical procedures, repeatability and subjectivity coming from tests with questionnaires. A humanoid robot with human-like structure and shape has potential to be used as an "active mannequin." By reproducing human motions based on a technique called retargeting, a humanoid robot can test wearable devices instead of a human. It has advantages as it can repeat the same motions to test the product under the same conditions, and it has no ethical risks. The largest advantage is its capacity of quantitative evaluation by measuring joint torques, which allows direct validation of supportive torque generated by the device. By taking an example of a supportive wear "Smart Suit Lite" supporting the user's lower back by elastic bands, we will overview the evaluation framework of humanoid-based assistive device evaluation, including human motion retargeting, experimental device evaluation with humanoid HRP-4C, and validation of the accuracy of the results using an identification method.

Key words: Humanoid, Assistive Devices, Evaluation, Parameter identification

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1 Introduction

Assistive devices for elderly people to maintain their vitality in daily life and other activities are drawing particular interests in such countries as Japan that is rapidly becoming a super-aging society. Those devices are also useful to reduce the load of the caregivers who often suffer from chronic lower-back pain. Japanese government has been conducting "Robotic Devices for Nursing Care Project" [23] to encourage wide diffusion of advanced assistive devices enhanced by robotic technology in not only nursing facilities but also at home for everyday life. Several private companies have already started developments of various assistive devices, especially wearable devices designed to help people move easily [24] or to reduce the load of caregivers [13, 25, 7].

One of the important issues is how to evaluate the physical effects of such assistive devices in a quantitative manner. The usual approaches so far are qualitative methods with human subjects such as questionnaires, sometimes combined with indirect dynamics estimation like motion capturing or physiological measurements such as EMG. Using human subjects not only requires clearing ethical issues, which often lead heavy approval procedures, but also coping with noise and error of those measured data.

We therefore propose a new application of humanoid robot for this purpose, using it as a reliable "subject" that reproduces human motions to evaluate those devices. Humanoid robots have advantages that they can reproduce human motions using the devices, provide quantitative measures such as applied torque or force from sensors, and repeat the same motions precisely.

As related work, Takanishi et al. reported usage of their humanoid robot Wabian-2R to evaluate and to suggest design improvements for walk-assist machine that the human user grips the handle to support their body with their arms [20, 21].

In this chapter, we present evaluation of wearing-type assistive devices that are closely attached to the human body, by generating humanoid motions that reproduce those of human as faithfully as possible. The approach has been applied to a passive assistive device "Smart Suit Lite (SSL)" [7] to quantitatively assess the supportive effect for various motions [15, 6]. Technical challenges for this device evaluation include the human-like motion reproduction, estimation of supportive effects of the device as well as validation of the results measured with the humanoids. We here employ HRP-4C [10] and HRP-4 [9] whose dimensions of links and bodies are within 10 % of average data of young Japanese women. In this paper we therefore focus on human motion reproduction and quantitative evaluation of supportive devices. We will also validate the results through a technique of dynamic parameter identification [2].

In this Chapter, after addressing the advantages of using humanoids for assistive device evaluation, we present several cases of evaluation of SSL for different motions. Finally we will describe the validation of the presented quantitative evaluation based on physical parameters identification.

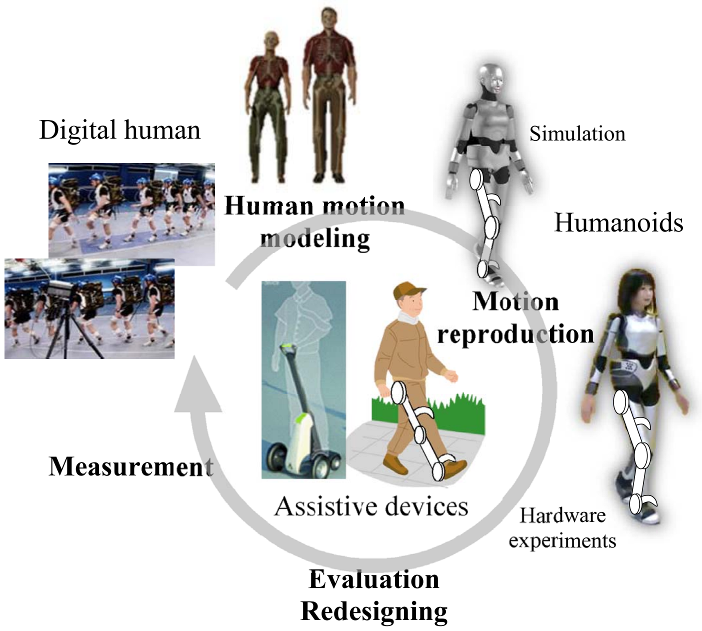


Fig. 1 Evaluation of assistive devices using humanoid

2 Humanoid Robot as Device Evaluator

The most common method for evaluating products for humans is to let human subjects use and test them and to get feedbacks through physiological or biomechanical measurements or questionnaires. However, the problems that make human subject experiments difficult are the following:

- Recruiting a sufficient number of subjects in specified range of gender, age, degree of disability.
- Reproducing the same motions for specific evaluation
- Difficulty in quantitative evaluation with human measurement and questionnaires
- Going through rigorous ethical procedures

To address those problems, we aim at developing a methodology of using a humanoid robot instead of human subjects to evaluate assistive devices. The expected advantages this replacement are the following:

- As humanoid robots have the same morphology as humans, they can physically simulate usage of the device in real life in a similar manner to humans.
- Humanoid robots can repeat exactly the same motions and provide quantitative measures such as joint trajectories, torques or applied forces.
- Ethical problems can be cleared for experiments with risks of injury.

Figure 1 shows how the humanoid robot can be integrated in the loop of product design and development of assistive devices. Even though the final evaluation is made by humanoid robot, it is important to collect some sample human motion data at the beginning phase of the development. We then apply suitable modeling methods to the measured motions to express them with appropriate parameters according to the performance indicator to be evaluated. Representative joint trajectories during several motions such as lifting or twisting are extracted in our case of supportive device.

Finally the parameterized motions are converted so that they can be reproduced by the humanoid robot. The physical motion execution makes it possible to test the assistive device from various aspects by assessing various quantitative measures. Since joint torque is always difficult to be measured or computed from captured human motions, we have a strong advantage in being capable of getting these data directly from the robot in real life.

Although accurate simulations may allow evaluation with different parameter settings and product configurations, there is still complexity in the interaction between the device and human that cannot be completely modeled. Experiments are therefore extremely important to evaluate the assistive devices by reproducing the real situation of its usage using a humanoid that allows comparing the performance with and without the device.

For quantitative evaluation of the supportive effect of the devices, accurate measurement or estimation of physical indicator, especially joint torque, is required. Joint torque is an important mechanical quantity when evaluating the assistive devices, since the role of many devices is to reduce the load applied on the joints of a human body.

Based on a technique called “motion retargeting” converting human motion to humanoid robots, [14, 17, 1], they are expected to reproduce the motions sufficiently close to those of human. If joint torque measured from the humanoid with those reproduced human motions is accurate, it can be used as a quantitative performance indicator of the assistive device by computing its supportive torque. A framework of the evaluation is therefore proposed by utilizing the identification of mechanical properties of a humanoid robot. The method for identifying simultaneously the parameters of the whole body dynamics, the actuator model, and the friction model is proposed.

3 Human Motion Measurement and Retargeting

In order to ensure the situation close to actual human usage of wearable devices, the humanoid is required to reproduce measured human motions as faithfully as possible. Motion capture data is widely used for creating the motion of human-like characters in the field of computer graphics [5]. In the field of robotics, some studies demonstrated their created motion on a real human-like and human-sized robot. Japanese traditional dancing has been realized on humanoid HRP-2, based

Fig. 2 Assistive suit “Smart Suite Lite” supporting the load of upper body by elastic band on the back [7]

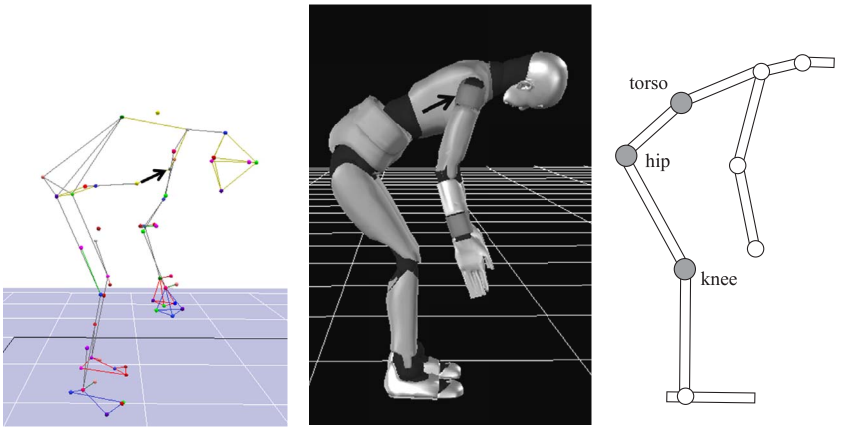
Fig. 3 Human motion measurement with a motion capture system

on the motion capture data of a professional dancer [19] [18]. In this paper we use an efficient retargeting technique developed based on a similar idea [14], which is adapted to reproduction of whole-body motion preserving many kinematic and dynamic constraints for the humanoid. Readers are referred to Chapter **??** “Human Motion Imitation” in Part “Huamnoid Motion Planning” for various approaches for human motion imitation in more detail.

As mentioned earlier, we take SSL as a device for quantitative evaluation of supportive effect. It is designed to relieve the load at lower back through extending elastic bands equipped at the backside (Fig. 2). The wearer can avoid back pain while bending down for a long time or repeatedly, for instance in agricultural tasks or transportation service. The main purpose is to reduce the torque at the lower back, a lifting motion is measured and retargeted.

The motions used in this study were captured by Vicon Motion Systems, a 3D optical motion capture system with 10 cameras, with sampling rate of 200 frames per second. The subject was a male adult and wore 55 optical markers as appropriate on his body, as shown in the Fig. 4a. He held a 3kg dumbbell in his both hands, stood with his feet shoulder-width apart, and bent down.

The output of the motion capture system consists of trajectories taken by markers placed on the performer’s body. A pair of markers forms a vector, as shown in Fig. 4a, which was matched with each of the link vectors of the robot illustrated in Fig. 4b. The joints we will focus on is illustrated in the simplified like model in Fig. 4c. We will later investigate the torque at the joints at the torso and hip that are used to lift the upper body and also supported by the assistive device. Although this simplified model does not completely model the mechanical structure of especially the human’s spinal cord, it is actually often used in biomechanics research, for instance to estimate the load in lower back [26]. The joint configuration of HRP-4C is at least close to that of those models.



(a) (b) (c)

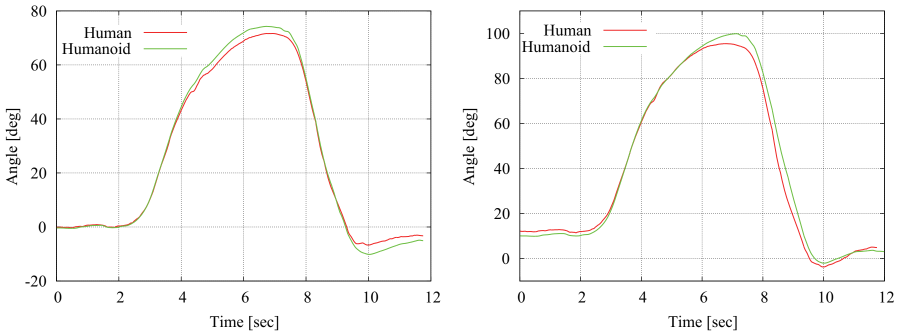
Fig. 4 A snapshot of captured motion: (a) View of captured markers, (b) Generated pattern of HRP-4C, and (c) joints in the simplified link model.

Offsets are added to the reference vectors, assuming that the human upper body and waist to be perpendicular to the floor at the beginning of the performance. Joint angles of both the arms and the chest of the robot were determined iteratively by minimizing the square sum of direction error between the vector of the pair of markers and the link vector of the robot.

The angles of the leg joints and torso joints of the robot were also obtained by iterative computation for solving inverse kinematics (IK) between the foot positions with respect to the position of the robot's trunk. The vertical displacement of the trunk, the joint angles obtained from the motion capture data, joint limits, and joint velocities were considered in null-space. The trunk position was modified by using the dynamics filter with preview control of ZMP [8] based on a cart-table model of invert pendulum, usually used for biped walking motion generation. As this approach imposes a constant height of the hip, we regard the movement of the hip height as an error within the allowable limits. Finally we obtain humanoid motions satisfying both dynamic consistency and preservation of the original human motion.

Generated humanoid motion is compared with the captured human motion data to validate the accuracy of reproduction. Although it is not possible to the make robot motion completely match the human's, we believe that the following two values are important to assess the capacity of motion reproduction for the evaluation of the assistive device: the inclination angle of the upper body that determines the load by gravity, and the relative angle between upper body and thigh that affects the extension of the elastic bands.

A comparison of inclination angle of the upper body between the performer and the robot is shown in Fig. 5a and relative angle (set to zero when the figure is completely upright) between the upper body and the thigh is also shown in Fig. 5b The average error during the motion was 1.62° and 2.86° respectively in Figs. 5a and



(a) upper body inclination angle (b) relative angle between upper body and thigh

Fig. 5 Comparison of measured human and humanoid motions

b. Those results show that the human and robot motions agree well with respect to above two values.

4 Evaluating Supportive Torque with a Humanoid

As mentioned in Section 2, the advantage in using a humanoid robot is its capability of quantitative evaluation that is difficult with tests with human subjects such as questionnaires. We may also measure EMG or apply dynamic analysis to measured human motions to estimate the joint torques. Although the former could provide a rough idea of generated force, the data are noisy and only come from the surface of muscles. The latter torque estimation can be a better measure, however it is difficult to precisely estimate dynamic activities that take place inside the human body based on external measurements.

Figure 6 shows the estimated joint torque of hip and knee using Visual3D™ from the lifting motion with and without SSL captured by Vicon motion capture system (torso joint is not included in the model). As can be seen, we cannot recognize significant difference between the two cases. This is because the resultant physical motion may be almost the same for both cases even though the human can move with less force thanks to the supportive torque generated by SSL. This result illustrates the limitation of dynamic motion analysis based on external measurement.

We have conducted experiments with HRP-4C [10] wearing SSL that that executes the converted lifting motion at Section 3. The snapshots of the motion are shown in Figure 7. We attached 1 kg weight at each wrist to simulate the lifting task. The closer view from the backside is shown in the upper row of Fig. 7. Those pictures show how the white elastic bands at the shoulders and thighs are extended

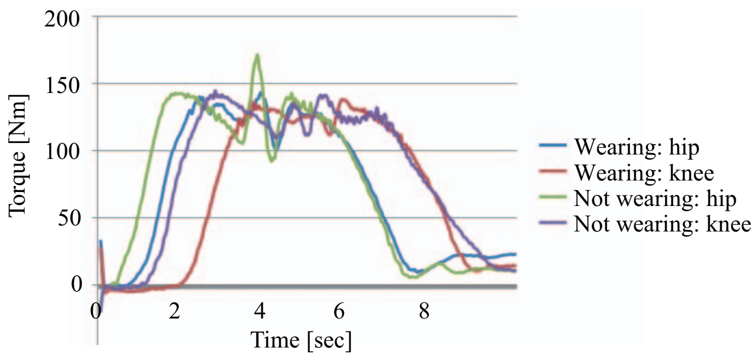


Fig. 6 Joint torque of human estimated through inverse dynamics computation from captured motion data

when the robot bends down. The lower row of Fig. 7 is the pictures of side view of the whole motion.

In order to evaluate the load reduction effect we compared the torque at the pitch joints at the torso and the hips for the motion with and without SSL. The joint torque is estimated from the current at the motor and reduction ratio through a filter removing high-frequency noise. Five trials were conducted for each condition.

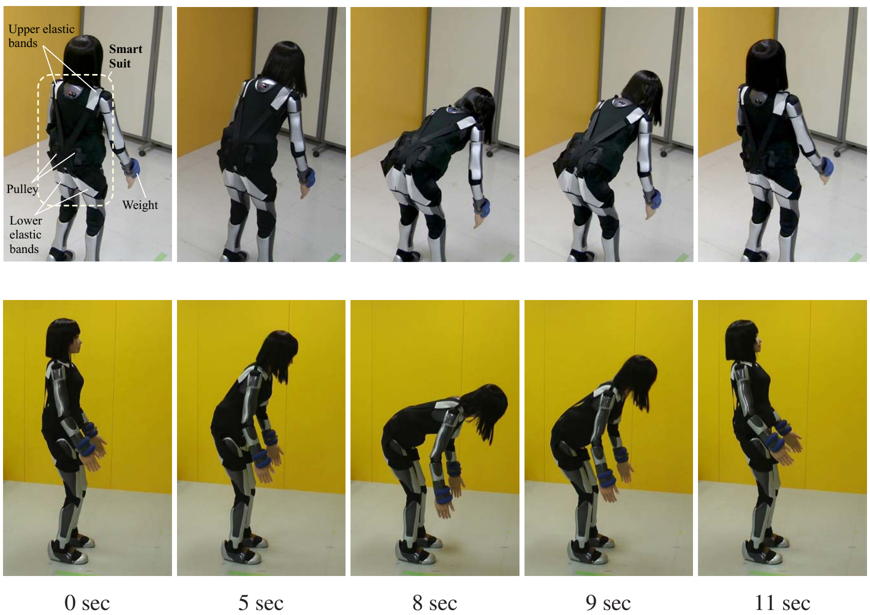
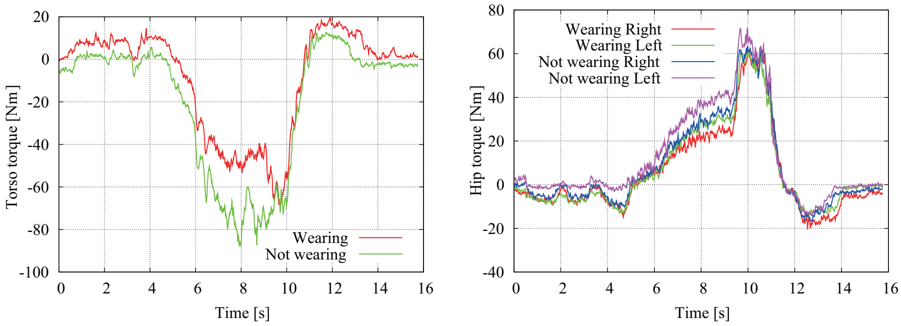


Fig. 7 Experiments of lifting motion by HRP-4C



(a) Torso torque (b) Hip torques

Fig. 8 Measured torque with and without Smart Suit.

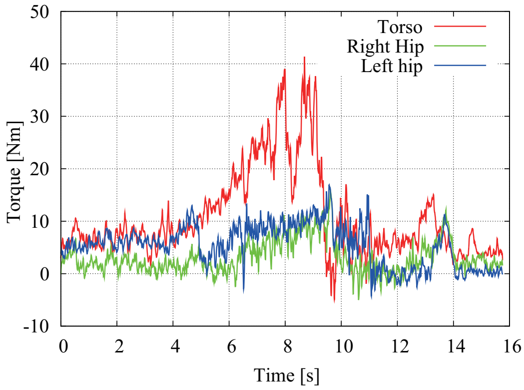


Fig. 9 Experimental result of supportive torque.

Figure 8 shows the measured torque at the pitch joints at the torso and the hip from typical trials of trials with and without SSL. The averaged maximum torque among five trials on each condition is listed in Table 1. The consistency of the assistive effect can be confirmed from Table 1 as there is high repeatability observed

Table 1 Maximum absolute torques during motion

		torso pitch	hip pitch	
			right	left
With Smart Suite	Mean	68.9	60.3	64.8
	Std. dev.	1.0	1.6	1.7
Free Motion	Mean	92.2	65.5	69.4
	Std. dev.	4.4	1.3	1.9

Unit: [Nm]

over all the trials. We also verified from the data log that wearing Smart Suit does not change the resultant joint trajectory of the robot, which means the effort itself for lifting the upper body is reduced. On the other hand, the difference of hip pitch joints between the results with and without SSL is not clear compared to the torso, as observed in Fig. 8b. Figure 9 shows the effective supportive torque computed from Figs. 8a and 8b taking its directions into account.

The experimental results imply that significant supportive torque is generated especially for the torso during the lifting motion and lead to quantitative evaluation of supportive devices by a humanoid robot. A question arises here is whether the estimated supportive torque is reliable as a quantitative measure. The next section addresses this issue based on an identification technique allowing validation of the estimated torque by the humanoid.

5 Validation of Measured Torque based on Identification

As seen in previous sections, joint torque is an important mechanical quantity when evaluating the assistive devices, since the role of many devices is to reduce the load applied on joints. The accurate measurement or estimation especially of joint torque is required. In this section, we present a framework of the evaluation by utilizing the identification of mechanical properties of a humanoid robot [2, 4]. The method identifies simultaneously the parameters of the whole body dynamics, the actuator model, and the friction model ,based on the identification of the inertial parameters of a humanoid robot [3].

A general modeling is introduced to compute the supporting torques of passive assistive wears like SSL by using the same formulation of the musculoskeletal computation [16]. We also present two approaches to estimate the supporting torque from the sensor data of a humanoid robot and compared the ground truth value using the stiffness directly measured with the assistive device. Figure 10 shows the pro-

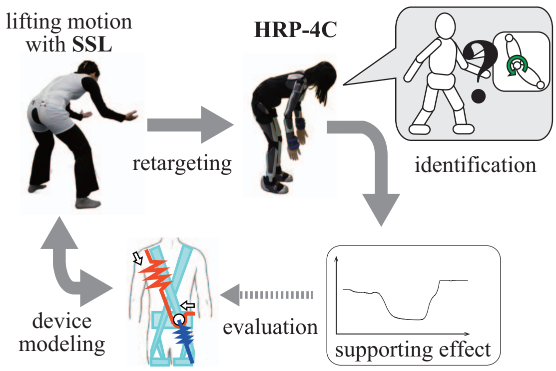


Fig. 10 Outline of the processes to evaluate assistive devices by using a humanoid robot

posed evaluation flow based on identification technique using the humanoid robot HRP-4C.

5.1 Modeling and Identification of Supportive Device

The accurate measurement or estimation of joint torques is important, which usually requires the joint torque sensors or the identification of the mechanical parameters of each joint. Even though the recent development of the torque sensors started being frequently utilized [22], some more technological advancement in hardware and control is still necessary to achieve whole-body torque control for a humanoid. The joint torques can be estimated from the inertial parameters, motor constants, gear-ratio, etc. provided by manufacturers. However, they are not necessarily accurate because of the uncertain elements like frictions, and can change when, for example, the robot carries the objects, the temperature condition of actuators changes, etc. We therefore introduced identification of those parameters as shown in Fig. 10, whose detailed procedure is described in Chapter **??** "Humanoid Identification" in Part "Humanoid Kinematics and Dynamics."

The equation of motion of the robot representing the joint torque $\boldsymbol{\tau}_{dyn}$ related to the actuator and supportive device is simplified as follows:

$$\boldsymbol{\tau}_{dyn}(\boldsymbol{x}^{with}, \boldsymbol{\phi}) = \boldsymbol{\tau}_{act}^{with} + \boldsymbol{\tau}_{support} \tag{1}$$

$$\boldsymbol{\tau}_{dyn}(\boldsymbol{x}^{without}, \boldsymbol{\phi}) = \boldsymbol{\tau}_{act}^{without} \tag{2}$$

where $\boldsymbol{\tau}_{act}$ and $\boldsymbol{\tau}_{support}$ represents the actuator torque and the supporting torque respectively, $\boldsymbol{x}$ denotes the robot's state like joint angles and their derivatives, and $*^{with}$ and $*^{without}$ the variable with and without the device respectively. Also, $\boldsymbol{\phi}$ represents the mechanical parameters of the robot. Two approaches are considered to estimate the supporting torque as shown in Fig. 11.

(A) Perform the same motions with and without the device respectively (i.e. $\boldsymbol{x}^{with} \approx \boldsymbol{x}^{without}$, thus $\boldsymbol{\tau}_{dyn}(\boldsymbol{x}^{with}, \boldsymbol{\phi}) \approx \boldsymbol{\tau}_{dyn}(\boldsymbol{x}^{without}, \boldsymbol{\phi}) \approx \boldsymbol{\tau}_{act}^{without}$), and compute the difference of joint torque between with and without the device:

$$\boldsymbol{\tau}_{support} = \boldsymbol{\tau}_{dyn}(\boldsymbol{x}^{with}, \boldsymbol{\phi}) - \boldsymbol{\tau}_{act}^{with} \approx \boldsymbol{\tau}_{act}^{without} - \boldsymbol{\tau}_{act}^{with} \tag{3}$$

(B) Compute the difference between the measured joint torques and those estimated from the mechanical parameters which were identified in advance:

$$\boldsymbol{\tau}_{support} = \boldsymbol{\tau}_{dyn}(\boldsymbol{x}^{with}, \boldsymbol{\phi}) - \boldsymbol{\tau}_{act}^{with} \approx \boldsymbol{\tau}_{dyn}(\boldsymbol{x}^{with}, \widehat{\boldsymbol{\phi}}) - \boldsymbol{\tau}_{act}^{with} \tag{4}$$

where $\widehat{\boldsymbol{\phi}}$ is the identified mechanical parameters by the dynamics model Eq. (2) and the motions without the device. The motions utilized in this identification

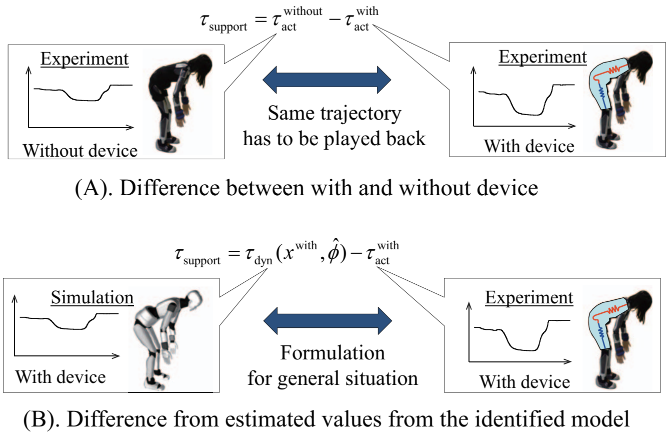


Fig. 11 Two methods for evaluating the supportive torque using humanoid robots.

process are not necessarily the same as those used for the validation with the device ($\boldsymbol{x}^{with} \not\approx \boldsymbol{x}^{without}$).

The strong advantage of approach (A) is canceling the unmodeled friction forces; on the other hand, the same motion has to be performed between with and without the device. The approximation in Eq. (3) holds by assuming that the state $\boldsymbol{x}$ is for the same for both motions. Some devices are originally designed so that the human should perform the different motion with and without them. Approach (B) is based on a general formulation and requires the accurate model of the robot (i.e. the identification of the parameters). Unlike approach (A), the supporting torque can be extracted directly from the recorded data with the device by approach (B) without comparing two motions.

After identifying the stiffness of SSL band from the experimental data of the robot, the obtained supporting torques for the device is evaluated at the final step.

Nominal modeling of supporting mechanism of assistive devices is of great importance in order to design, modify, and evaluate them. If a passive assistive device consists of several elastic bands or belts, the supporting torques generated at human joints can be modeled in the same manner as the formulation of wire-driven multibody systems. It is also related to the musculoskeletal analysis where the joint torques are generated by several muscles modeled as elastic wires [16]. Those techniques allows us to map the elastic forces to the joint torques based on an elastic model of the assistive device.

Each wire has several via points fixed on the rigid-body system. The supporting torques are formulated as follows:

$$\boldsymbol{\tau}_{support} = \sum_{i}^{N_l} \boldsymbol{J}_i{}^T f_i \tag{5}$$

where N_l is the number of wires, $f_i \in \mathbb{R}$, $\boldsymbol{J}_i \in \mathbb{R}^{1\times N_J}$ is the elastic force and the Jacobian matrix of length l_i of i-th wire respectively, N_j being the number of degree of freedom (DOF).

In order to represent the two SSL bands in Fig. 12 (left), eight viapoints per one band are placed on the surface of the model of HRP-4C as shown in 12 (right). Each viapoint is fixed on the corresponding link, and its position can be computed by the forward kinematics computation.

The elastic force of each SSL band is formulated as a linear spring as follows:

$$f_i = \begin{cases} -k_i(l_i - l_{0,i}) & (l \geq l_{0,i}) \\ 0 & (l < 0) \end{cases} \tag{6}$$

where l_{i0} is the natural length and k_i is the stiffness of SSL band i. The stiffness of each SSL band is $k_i = 197.8$ [N/m], which is identified by the experiment.

The supporting torques of SSL are computed from Eqs. (5) and (6). If the geometric parameters of the robot and the location of via points are known, $\boldsymbol{\tau}_{support}$ depends on the following constant parameters, stiffness k_i and natural length $l_{0,i}$. They can be identified from the estimated supporting torques by the following optimization problem:

$$\min_{\forall i\ k_i, l_{0,i}} \sum_t \left(||\widehat{\boldsymbol{\tau}}_{support} - \widehat{\boldsymbol{J}}_i \widehat{f}_i|| \right) \tag{7}$$

where $\widehat{\boldsymbol{\tau}}_{support}$ is the vector of the supporting torque, which is estimated from Eq. (3) or Eq. (4) and $\widehat{\boldsymbol{J}}_i$, while $\widehat{f}_i$ are estimated from measured motions of the robot and elastic bands. Since Eq. (7) has no equality or inequality constraints, the problem can be solved by, for example, the quasi-Newton method.

Fig. 12 Overview of SSL (Left) and its computational wire model (Right). There are two wires which respectively have eight via points attached on the robot.

5.2 Experimental Validation

We have used the experimental data obtained in Section 4 for validation. First, inertial and joint parameters of HRP-4C has been identified based on the method in Chapter **??** "Humanoid Identification" and then used to estimate the supportive torque. Fig. 13 shows the torque error of the pitch joint of the torso, which is expected to be mostly supported by SSL. The red and blue lines show the error when using the identified and a-priori parameters (the values provided by the manufacturer) respectively. The black dotted lines are the moment and the joint torque measured from the sensors, which are plotted in order to check the scale of the data. As can be seen from the figures, the identified parameters show better performance rather than the a-priori parameters.

The supporting torques of SSL were estimated by the two approaches in 5.1, implemented as follows:

(A) Compute the difference of joint torque between with and without the device: Eq. (3)
(B) Compute the difference between the measured torque and the torque estimated from the model: Eq. (4)

Note that approach (B) has an advantage that it can be applied in cases where the motions with and without supportive devices are not quite similar, since we only use the motions with the device.

Fig. 14 shows the comparison of the supporting torques of the pitch joint of the torso. The red and blue lines show the supporting torque estimated by approach (A) and (B) respectively, with the identified values. The green line represents the torque

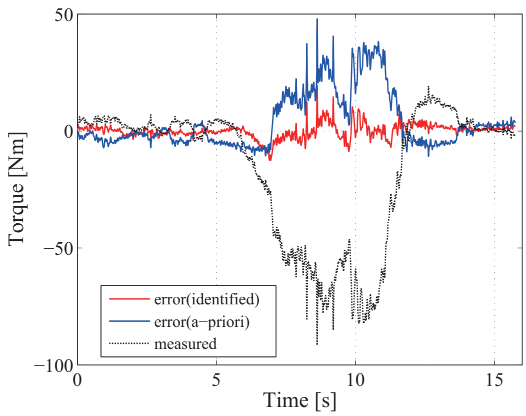


Fig. 13 Direct validation of the errors about the torque of the pitch joint of the torso: the error when using the identified parameters (red), the error with the a-priori parameters (blue), and the measured joint torque (black). The RMSE of the red line is 3.06 Nm, and that of the blue line is 12.50 Nm.

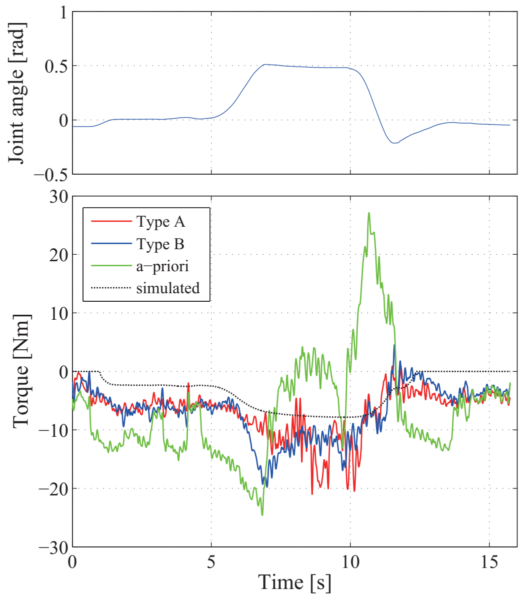


Fig. 14 Comparison of the torso joint torques: by approach (A) using the identified values (red), by approach (B) using the identified value (blue) and using the a-priori parameters (green), and by the SSL simulation with the ground truth stiffness (black).

estimated by approach (B) with the a-priori values. The black line shows the torque estimated from the SSL simulation described in 5.1.

Although there exists an offset, the red and blue lines shows the good correlation with the black line whereas the green line does not match the black line. The results demonstrate the supportive effect at the torso joint during the bending motion.

We evaluated the mechanical properties of SSL by using the supporting torques estimated from the sensors with the identification (14). The stiffness and the natural length of each SSL band were identified by solving Eq. (7). Table 2 shows the result of the identified stiffness of the SSL band; (a) the measured value, (b) the identified value by using the supporting torque estimated from approach (A), (c) the identified one by approach (B), and (d) the identified one by using the torque estimated from the a-priori values.

Table 2 Comparison of the stiffness of the SSL band.

	stiffness[N/m]
(a) measured value	197.8
(b) identified by approach (A)	187.0
(c) identified by approach (B)	242.2
(d) identified with a-priori model	55.9

Table 2 shows that the proposed scheme could successfully identify the mechanical property of the device. The results also indicate that the identification has a great role when we evaluate the device with a humanoid robot. The error of the identified value in case (A) is 5%, and the error in case (B) is about 20%. Although there is the strict constraint such that the same motion has to be performed between with and without the device, the case (A) showed better performance than case (B).

The error of case (B) is not small currently. That is mainly because the friction model cannot eliminate the effect of the sudden change between kinetic to static frictions; there is the error peak when the joint stops in Fig. 14. To exploit the advantage of approach (B) which needs only the motions with devices, improvements of modeling such as friction models will be addressed in our future work.

6 Future Direction and Open Problems

In this Chapter we presented methods for human motion retargeting using a humanoid robot and also for evaluation of devices interacting with humans. An evaluation framework using a humanoid robot has been established for wearable passive supportive devices, such as "Smart Suit Light" designed to reduce the load applied to human's lower back using elastic bands supporting the upper body. We have also developed a retargeting method that imitates human motions to reproduce the situation of real use of such devices.

The future development has two directions: an enhanced retargeting method and extension of applicable devices to evaluate by using a humanoid robot. First, the current retargeting technique only reproduces human motions. Recently, a method has been proposed that allows reproducing complex motions while preserving the dy-

Fig. 15 pneumatically powered assistive device "Muscle Suit" and the humanoid HRP-4 wearing it for evaluation.

namic features of the original motions [1]. This enables analysis of assistive device with more complex motions than lifting, for instance those including twisting [6]. However, such devices as walking assistance or power assisting suit have closer interaction including force than wearable passive devices like SSL we have evaluated in this chapter. A big challenge is to integrate dynamic features of human motion in the motion retargeting process to model the "human controller". As mentioned in 5.2, identification with more precise model for the assistive device and robot is also an issue to be addressed for evaluation.

The second target is to broaden the devices to be evaluated by a humanoid. Unlike passive ones, assistive devices generate powers to support human motion like lifting and walking. Based on the enhancement of retargeting technique mentioned earlier, we aim at developing a framework of evaluation of different powered active devices like "Muscle Suit" [12, 11] that help users to lift heavy objects using powerful pneumatic actuators as shown in Fig. 15.

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