Wearable Robotics as a Behavioral Interface
-The Study of the Parasitic Humanoid-

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Abstract

The Parasitic Humanoid (PH) is a wearable robot for modeling nonverbal human behavior. This anthropomorphic robot senses the behavior of the wearer and has the internal models to learn the process of human sensory motor integration, thereafter it begins to predict the next behavior of the wearer using the learned models. When the reliability of the prediction is sufficient, the PH outputs the errors from the actual behavior as a request for motion to the wearer. Through symbiotic interaction, the internal model and the process of human sensory motor integration approximate each other asymptotically.

Key Words: *wearable computing, nonverbal, behavior model, humanoid*

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1. Introduction

Most wearable computers today derive their usage from concepts in desktop computing such as data-browsing, key-typing, device-control, and operating graphical user interfaces. If wearable computers are anticipated to be fitted continuously as clothing, we must re-examine their use from the viewpoint of behavioral information. In this paper, we consider the role of wearable computers as a behavioral interface.

In this paper, we consider wearable computing applications which rely on the advantage of embodiment as a primary medium of the interface. The term Parasitic Humanoid (PH) refers to wearable robotics adapted to such applications. Section 2 presents the advantages of PH as a symbiotic interface for nonverbal human behavior, and three motivations for the use of PH. Section 3 presents several scenarios of symbiotic interaction, and how the relevant techniques are implemented through PH, and Section 4 presents the prototype of PH which we are now developing. Finally in Section 5 we comment on future research and conclude.

Proceedings of the 6th International Symposium on Wearable Computers (ISWC'02)
0-7695-1816-8/02 $17.00 © 2002 IEEE

2. Wearable Robotics as Behavioral Interface

Wearable computing and wearable robotics have separate histories. Most recent research on wearable robotics is motivated by interest in powered assist devices [3]. These devices are typically too heavy and consume too much energy for mobile use. On the other hand, research in mobile wearable robotics [10] does not take advantage of the embodiment of wearable devices.

2.1. The Usage of Anthropomorphic Robots

Consider the usage of anthropomorphic robots as an interface for human behavior. This is perhaps the only pragmatic usage, because the anthropomorphic shape is usually disadvantaged compared to optimized designs for other purposes. One successful example is the Telexistence system [12]. However, such a robot is too complicated and expensive to be an interface of human behavior, and therefore too socially unacceptable to be considered as a pragmatic solution, except for some specific purpose, such as teleoperation of robots in a hazardous environment (although commercial systems are quickly driving down the cost of such devices). A more serious concern regards the safety for the users under common circumstances in modern lifestyle.

There will be situations of disorder in which the control system of the robot continues to move although it has to stop to avert a collision. A solution in this situation is a lightweight and low power design such that a surveyor can easily prevent undesirable motion. However, this strategy makes it difficult for the robots to support themselves.

2.2. Wearable Robotics without Powered Assist

Wearable sensory devices can construct a wearable humanoid without muscles and skeletons, if they are of the proper type and in sufficient number (Fig.1).

This robot may be too weak to move by itself, and can not assist the wearer with mechanical power. However, it is safe and light for the wearer, and can assist him or her with various behavioral information, when the worn robot is continuously capturing, modeling and predicting the behavior of the wearer.

2.3. Parasitic Humanoid

We refer to such a wearable robot as Parasitic Humanoid (PH). PH is a wearable robot for modeling nonverbal human behavior. This anthropomorphic wearable robot senses the behavior of the wearer and has internal models to learn the process of human sensory motor integration, thereafter it begins to predict the next behavior of the wearer using the learned models. When the reliability on the prediction is sufficient, the PH outputs the errors from the real behavior as a request for motion to the wearer. If the correction is inappropriate, the wearer will not follow it, and the PH corrects its internal model by the error and continues learning. In contrast, if the correction is appropriate, the wearer follows the correction and corrects his or her own internal behavioral model. In this case, the PH does not correct its internal model and raises the estimation of the model's reliability. Through this symbiotic interaction, the internal model and the process of human sensory motor integration approximate each other asymptotically. As a result, the PH acts as a symbiotic subject for information of the environment. The relationship is similar to that of a horse and the rider, although the role of the wearer corresponds to the horse, not following like a sheep. The symbiotic relationship between these partners acts as a high performance organism.

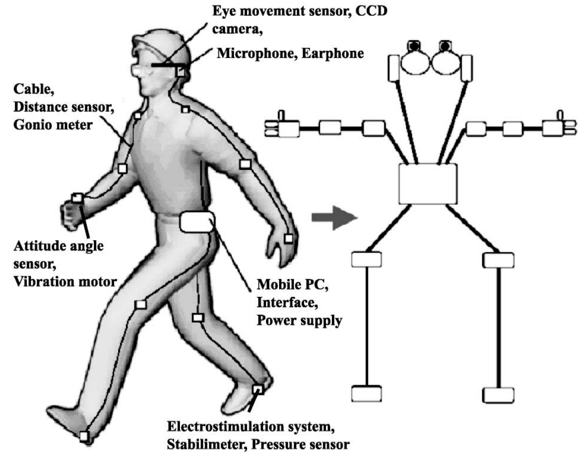

Figure 1. Wearable sensory devices construct a wearable humanoid without muscle or skeleton

3. Scenarios for Symbiotic Interaction with Parasitic Humanoid

3.1. Capturing and Retrieving the Best Behavior

The most direct usage of PH as a behavioral interface is capturing and retrieving behavior. It is not only for scientific research to analyze human behaviors, but also to enhance daily life. When you play golf, you may want to capture and retrieve your best shot. Otherwise you may download the data of the swing from the PH of Tiger Woods. You may exchange data for dance steps like name cards in a ballroom. Behavioral interfaces will make up the new style of

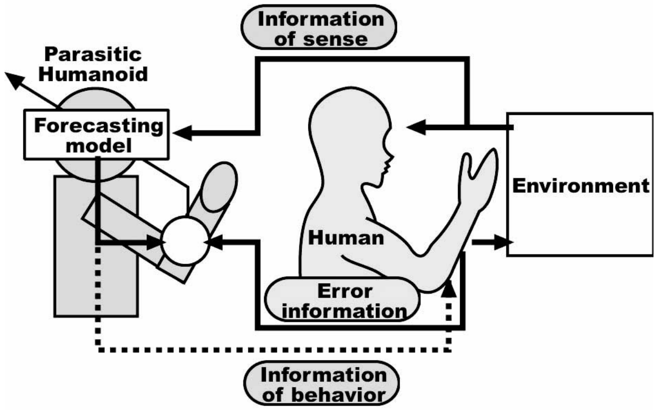

Figure 2. The symbiotic relationship between the wearer and the Parasitic Humanoid

communication.

3.2. Dual Consciousness After Continuous Capture of Sensory Stimuli and Behavior

Consider PH's recording a continuous history history of each wearer, and adapting to their individual habits and styles. When the history includes sufficient patterns of daily behavior, the wearer can behave as if he or she has dual consciousness. He may be induced to avoid oncoming cars from behind unconsciously when the PH is aware of their presence. If the PH is linked to a traffic information site, his driving may avoid and suppress traffic jams unconsciously. The wearer is free from verbal information that is distracting for continuous behaviors.

3.3. Adaptation to Individuals: Modeling for Prediction in Behavior & Self-Organized Mapping for Motion Analysis

Perhaps the ideal interface is one that completely adapts to each individual user. However, it is intractable for artificial devices to learn parameters for adaptation automatically. PH provides a solution by not only adapting to the user but also requesting the user to adapt to its internal model. As a result, the internal model does not require so many complex and unstable parameters.

In essence, we are designing the nervous system in Parasite Human. It uses sensory information to produce a model of body structure by performing self-organized learning. This model performs information integration between motor systems and sensory systems. PH requires human action according to the model. We apply a neural oscillator as the motor command generator, multi-layer perceptrons for the sensory integration of spatial information to generate the next behavior, and Self-Organized Mapping (SOM) neural networks [6] for the segregation of sensory signals in behaviors (Fig.3, 4). Fig.4 is an example of self-organized mapping to segregate walking behaviors in four speeds, such as walking slowly (WS), walking normally (WN), running slowly (RS), and running normally (RN). The inputs for the SOM are the joint angles of the knee and the hip in the right and the left legs. In this case, the cells of the center area have been encoding the two states of walking, and the other cells around them have been encoding the two states of running.

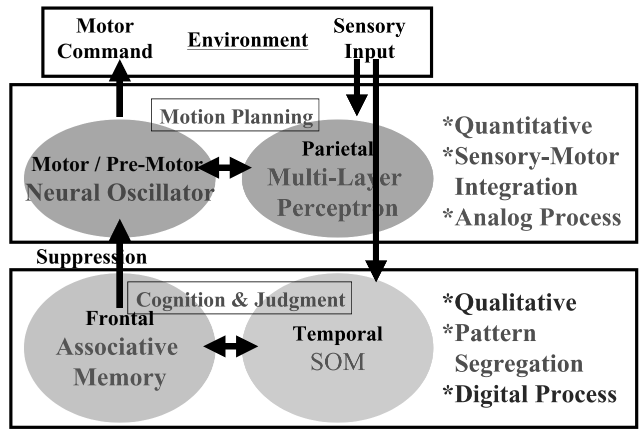

Figure 3. Paradigm of nervous system of Parasitic Humanoid

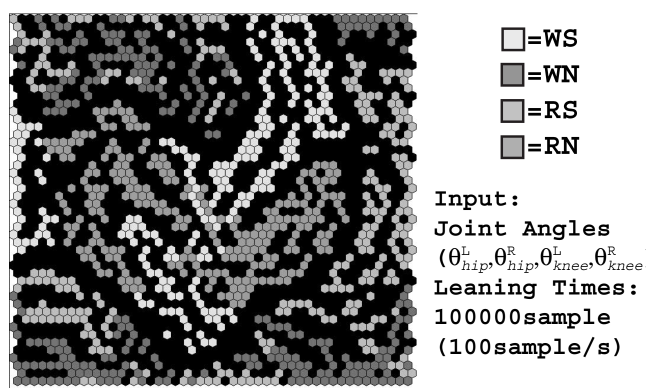

Figure 4. Example of self-organized mapping to segregate walking behaviors in four speeds

3.4. Symbiotic Behavior by Motion Induction

A request for user motion is not enforced but rather induced by PH. The method of motion induction is based on the concept of entrainment in the neural oscillator [2] [9] (Fig.5). The parade march is the typical stimulus. Therefore, our research focuses especially on walking movement based on a neural oscillator model [13]. Using this model, we can induce the walking cycle of the wearer. If arms or insteps are stimulated by cyclic vibration, usually we won't pay any attention to it. But if the cycle of vibration is similar to a walking cycle, the vibration influences the walking rhythm to mimic that of the vibration. Fig.6 is an example of the motion induction of a walking sequence. The normal human walking cycle is very stable, with an average deviation of less than approximately 1-2 % of the cycle. In this experiment, the vibration stimuli to the insteps started just after the 30th step. Until the 60th step, the stimuli synchronized the steps of the wearer. Then, the tempo of the stimuli was increased, followed by the cycle of walking. In this experiment, the effective induction succeeded up to within approximately 5 % of the cycle.

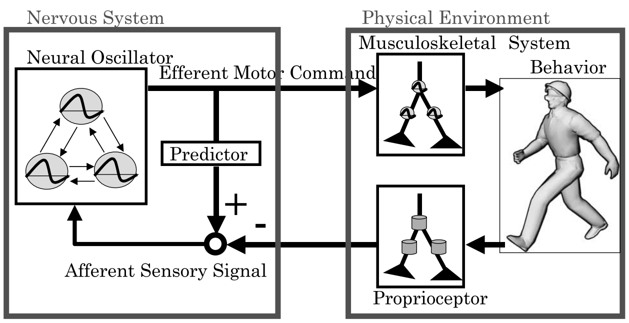

Figure 5. Paradigm of motion induction in neural oscillator model of Parasitic Humanoid

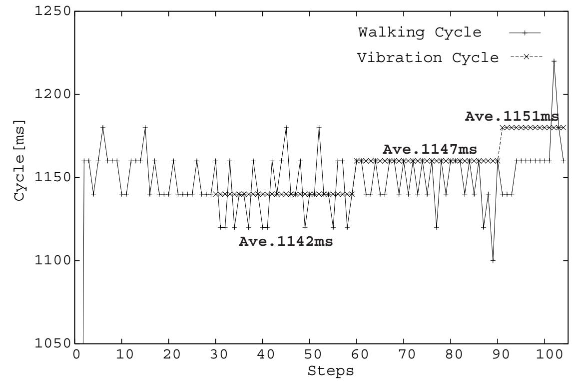

Figure 6. Example of motion induction in walking sequence: after the 20th step

Figure 7. The Prototype of Parasitic Humanoid

4. Elements Constructing Parasitic Humanoid Under Development

In this section we outline each part of the device technologies constructing PH, which are both wearable devices and behavioral interfaces.

4.1. Prototype Hardware

The prototype of Parasitic Humanoid is shown in Figure 7. This system consists of vibration motors and sensors in Table 1, which observe sensory inputs and behavior outputs of the wearer. The total weight of motors, sensors and wirings is less than 500g. Signal transmission to the mobile PC uses USB standards. The CPU performances of typical mobile PC's are sufficient for logging the sensory data, controling the vibrators, and learning the internal neural network models, when the usage is a limited experiment to partial system of PH (Fig.8).

This system has over one hundred inputs, and less than thirty outputs. As such, the balance of I/O is clearly input heavy, because the internal model is under development and the optimal arrangement of vibrators to attach to the wearer is not clear yet. Several methods of stimulus for motion induction are currently under development and evaluation.

4.2. Wearable Limb Motion Measurement System

For measurements of limb motion, the PH uses the 3-axis postural sensor manufactured by TOKIN Corporation. This sensor includes three rate gyros, two axis sensors for the direction of gravity, and two magnetic compasses. This sensor has an advantage that the wearer has no devices

Type of Sensors	Configuration of Sensors	N of Signals
3-Axis Postural Sensor	Head: 1, Trunk: 3, Each Limb: 3	16 *3 = 48
Fingernail Sensor	Bending and Touching of 3 Fingers in Each Hand	3 *3 *2 = 18
Eye Movement Sensor	Each Eye 2-Axis Motion and Size of Pupil	3 *2 = 6
Shoe-Shaped Sensor	Pressure: 5 points, & 1 Impact Sensor in Each Foot	6 *2 = 12
Audio & Visual Sensor	2 CMOS Camera (120Hz) & 2 Microphone	2Video +2Audio

Table 1. Sensors in Prototype of Parasitic Humanoid

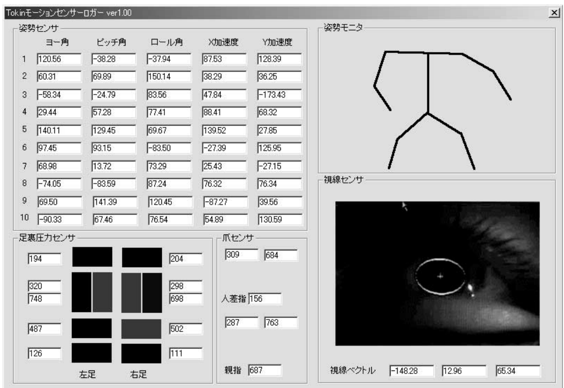

Figure 8. Example of Information Monitor from Sensors

attached to the joints because this sensor senses not relative postures but absolute postures of limbs. As a result, the influences to behavior by the presence of motion sensors must be minimized. The sampling rate is 100 [Hz], and the angular resolution is 0.1[degree].

4.3. Wearable Eye Movement Measurement System

Before picking up a cup, we typically look at it first. Moreover, before we move somewhere on foot, we usually look at our destination. Thus, by catching both eye movement and behavior, perhaps we can understand the relation of both. Further, if that relation is known, the next action could possibly be predicted through eye movement. The most important point of PH is to not hinder human behavior during measurement. Our goal is to measure the gaze position in 3-dimensional space from the center of both eyes up to the hand's reaching limits (about 0.7 [m]), according to the angle of convergence, and within an error of 20 [mm]. The sampling rate was set to 100 [Hz], because a rapid sequence of real-time measurements of eye movement and other movement systems (arm position) is important for be-

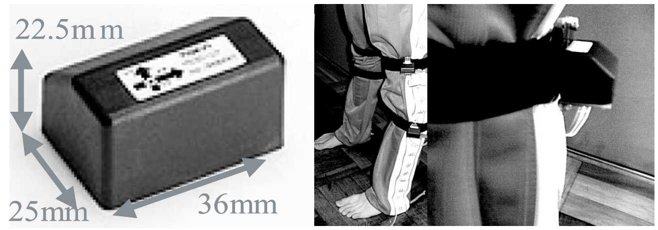

Figure 9. 3-axis Postural Sensors for Limb Motion Measurement

havior analysis [5]. From the relation between convergence and gaze position, the accuracy of eye movement detection must be high, i.e. around 0.1 [deg], especially if the gaze position becomes distant.

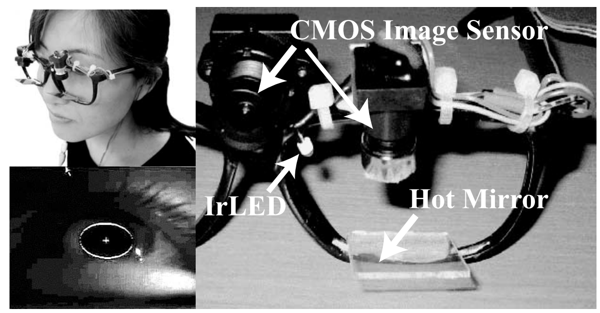

Figure 10. Wearable Eye Movement Measurement System

4.4. Fingernail Sensor: To Measure Direct Touch with Fingertip

We propose a novel fingernail sensor for detecting the touching and bending of the finger. This sensor is placed on the fingernail to avoid hindering the direct touch of the fingertip. The sensor consists of miniature light emitting diodes (LEDs) and photo-detectors, which measure the force at the fingertip and the bend of the finger through the intensity of scattering reflection as the finger's color changes. This instrument is wearable and practical for daily use. Furthermore, since the reflection's measurement is taken from the side of the fingernail, it does not obstruct natural movement of the wearer [4] [7] [8]. Fig.12 is an example of the response to cyclic contacts (cycle: 1.0[Hz], interval: 0.5[s], contact force: 0.5[N]). The response has sufficient repeatability without delay to detect contacts of the fingertip. We have already applied this technology to Smart Finger [1], which is a new type of display that provides supplementary tactile sensations for augmented reality. For example, someone wearing this small device on his or her nail can touch a drawing on a flat sheet of paper and feel a virtual edge along the drawing's line, and virtual roughness from its texture pattern. In this device, the fingernail sensor extracts a force vector due to the various color patterns of the nail corresponding to the contact force direction. It can measure force up to approximately 2[N] [11].

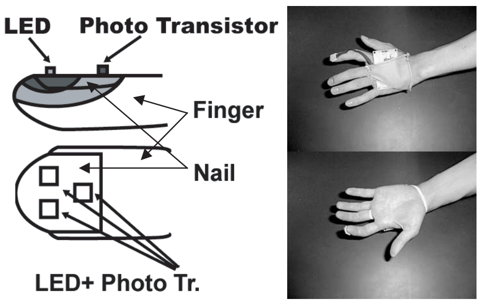

Figure 11. Fingernail Sensor

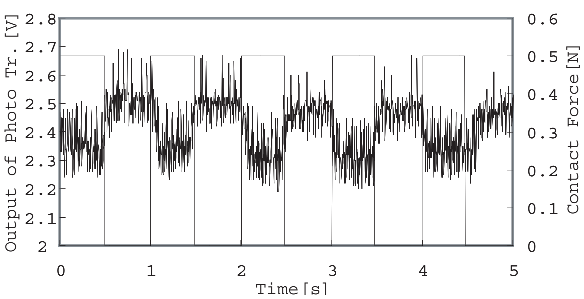

Figure 12. Example of the response of Fingernail sensor to cyclic contacts

4.5. Shoe-Shaped Sensor: To Measure Walking and Standing

Presented here is a shoe-shaped interface designed to induce a specific walking cycle. An individual's walking cycle is measured with a pressure sensor on the sole of the shoe, and a vibration motor attached on the instep stimulates the foot with cyclic vibration. We found that stimulating the instep with cyclic vibration, does not obstruct normal walking movement, and that if the cycle of vibration is similar to that of a walking cycle, the vibration influences the walking rhythm to mimic that of the vibration.

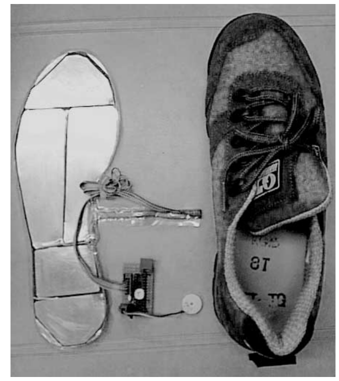

Figure 13. Shoe-Shaped Sensor

5. Conclusion and Future Direction

We have presented a survey of several interaction techniques and interface technologies that are useful for the design of Parasitic Humanoid. Desktop computers come equipped with large monitors providing high bandwidth output and essentially obviate the need for nonverbal output. Similarly the keyboard does not accept the need for nonverbal input. Wearable computing changes the picture dramatically, since traditional interfacing components are not incorporated as easily. We suggest that this is an ideal area to integrate behavioral information as a primary interface medium.

Most of the work we have reviewed in this paper are areas of ongoing research. To conclude we would like to highlight two areas which are particularly challenging but important to consider. Given the personal nature of wearable computers, adaptive interfaces will be especially important. If the computer is to be as natural as clothing, it must be as malleable to the particular whims and idiosyncrasies of each user. Natural interaction methods for interfaces that adapt to the habits and styles of each user is an open area of research, and Parasitic Humanoid will be a solution for the problem.

Finally, in the future, PH must be not only have an interface to the wearer and the environment, but must have an interface to another computer or network. PH becomes a more adaptive interface to the continuing wearer day by day, because PH is learning the behavioral model of the wearer. As the result, PH is suitable as a medium of nonverbal and behavioral communication. For example a PH could capture and record the swinging motion of a best shot. The behavioral data is useful not only for the wearer to remember the swing, but also for another wearer of PH to learn the better play. Thus the PH must have some behavioral translation to generalize the skill of the wearer.

References

[1] H. Ando, T. Miki, M. Inami, and T. Maeda. The nail-mounted tactile display for the behavior modeling. *Conference Abstracts and Applications of SIGGRAPH 2002*, San Antonio, U.S.A., July 2002.

[2] S. Grillner. Neurobiological bases of rhythmic motor acts in vertebrates. *Science*, 228:143–149, 1985.

[3] S. Jacobsen. Wearable energetically autonomous robots. *DARPA Exoskeletons for Human Performance Kick Off Meeting*, 2001.

[4] R. S. Johansson and G. Westling. Role of glabrous skin receptors and sensorimotor memory in automatic control of precision grip when lifting rougher or more slippery objects. *Exp. Brain Res*, 56:550–563, 1984.

[5] K. Kansaku, S. Kitazawa, and K. Kawano. Sequential hemodimamic activation of motor areas and draining veins during finger movements revealed by cross- correlation signals from fmri. *Neuroreport*, 9:1967–1974, 1998.

[6] T. Kohonen, J. Hymminen, J. Kangras, and J. Laaksonan. Som pak: The selforganizing map program package. *Technical Report A31, Helsinki University of Technology*, 1996.

[7] S. Mascaro and H. Asada. Distributed photo-plethysmograph fingernail sensors : Finger force measurement without haptic obstruction. *Proceedings of the ASME Dynamic Systems and Control Division*, DSC-Vol.67:73–80, 1999.

[8] S. Mascaro and H. Asada. Photoplethysmograph fingernail sensors for measuring finger forces without haptic obstruction. *the IEEE Transactions on Robotics and Automation*, 2000.

[9] K. Matsuoka. Mechanisms of frequency and pattern control in the neural rhythm generators. *Biological Cybernetics*, 56:345–353, 1987.

[10] W. W. Mayol, B. Tordoff, and D. W. Murray. Wearable visual robots. *International Symposium on Wearable Computing*, 2000.

[11] Y. Nomura and T. Maeda. The study of fingernail sensors for measuring finger forces and bending. *Journal of The Virtual Reality Society of Japan*, 6, No.3, 2001 (In Japanese).

[12] S. Tachi, H. Arai, and T. Maeda. Tele-existence simulator with artificial reality(1) - design and evaluation of a binocular visual display using solid models. *IEEE International Workshop on Intelligent Robot and Systems (IROS'88)*, October 1988, Tokyo, Japan.

[13] G. Taga. A model of the neuro-musculo-skeletal system for human locomotion. *Biological Cybernetics*, 73:99–111, 1995.