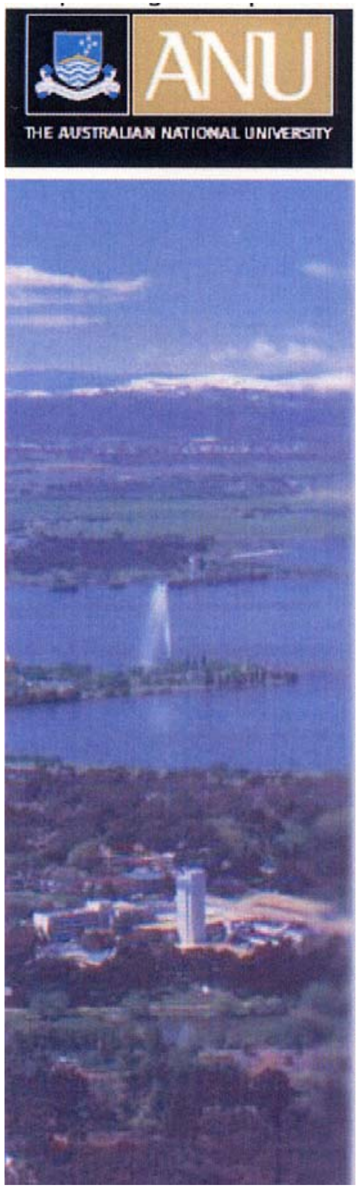
Advanced 9
Rehabilitation and Life Science Technology

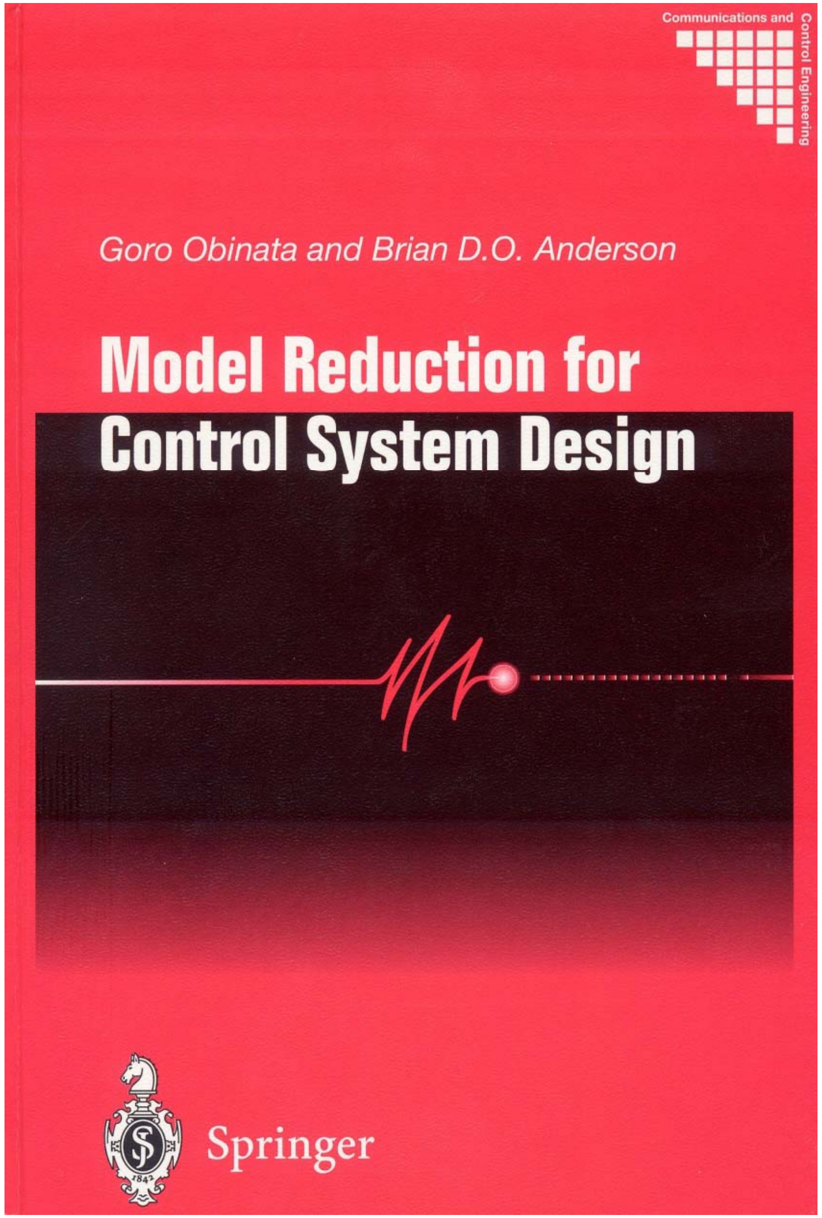
Prof. G. Obinata and Assistant Prof. C. Nagai
Dept. of Mechanical Science and Engineering
Nagoya University

Contents

- My short history from engineering to rehabilitation
- Progression of robotics
- Model based approach
- Results
- Human and robot

Visiting Position in Canberra





Across with a orthopedist

讀賣新聞

歩行補助ロボット開発

秋田大研究者ら　初の自走式、実用化期待

「より楽に」追究　介護者の負担軽減にも

秋田大学と県工業技術センターの研究者らが、交通事故などで歩行が困難となり、筋肉に電気刺激を与える「機能的電気刺激」（FES）を使用している人の歩行を助けるロボットをこのほど開発した。FESと連動させて歩行を支援する自走式の器具は、全国でも初めて。

開発したのは、同大の大日方五郎工学資源学部教授と、島田洋一医学部助教授、県工業技術センターの研究グループ。

大日方教授らによると、脊椎（せきつい）損傷などで足の動かなくなった人は、足の筋肉は正常だが、脳からの経路が断たれ、筋肉を動かすための電気刺激が行えなくなる。FESは、その電気刺激をコンピューターが代わりに行うもので、つえなど体を支える器具の助けを借りて、歩く動作を引き起こすことができる。ただ、従来のFESは疲れやすく、微妙な制御が困難なため転倒しやすかった。

これらの欠点を補うために開発された歩行ロボットは、患者を支える器具を自走式にし、患者がよりスムーズに歩けるようにした。

実験は、昨年十一月中旬、県工業技術センターで行われ、交通事故で両足が動かなくなった三十代の男性が、歩行ロボットの力を借りながら、約五メートル歩くことに成功した。

人間の歩行速度は一様ではなく、より楽に歩けるようにするには、ロボットにも一歩ごとにブレーキをかける動作が要求される。実験の結果、器具がじわりと止めるブレーキ力を備えれば、実用的になることが分かった。

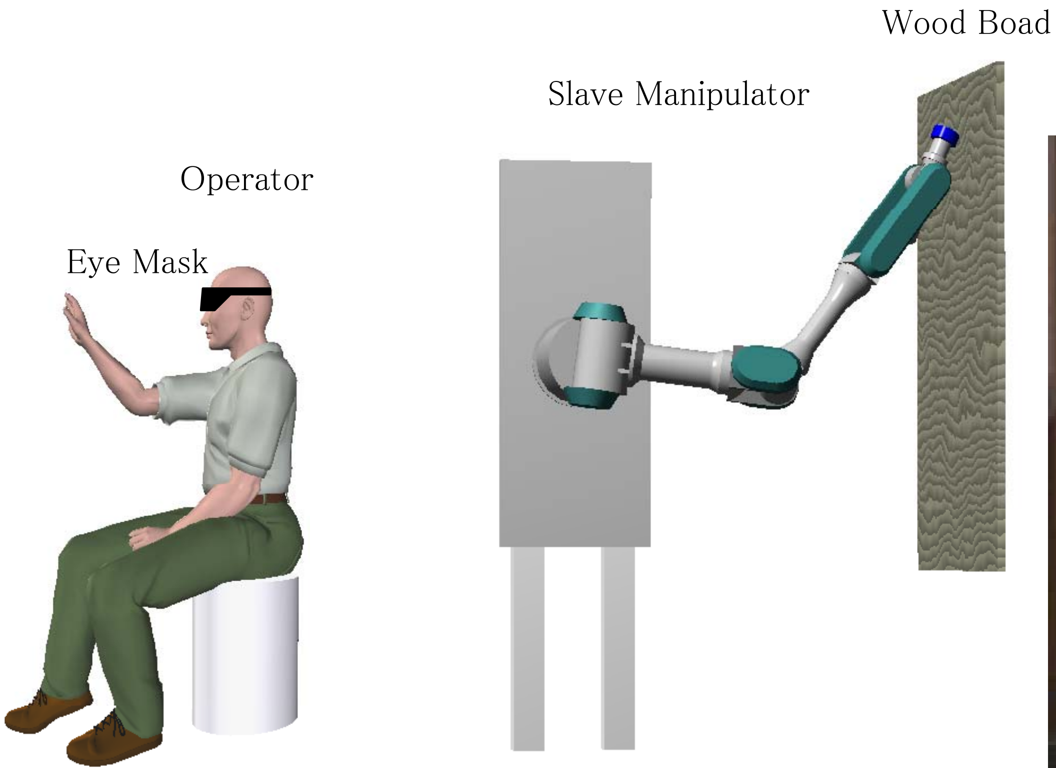
大日方教授は「最大の問題は、重くてごついこと。屋内使用のためには、小型・軽量化が必要。改良を重ねて実用化できれば、介護者にとっても負担が軽減される」と話している。

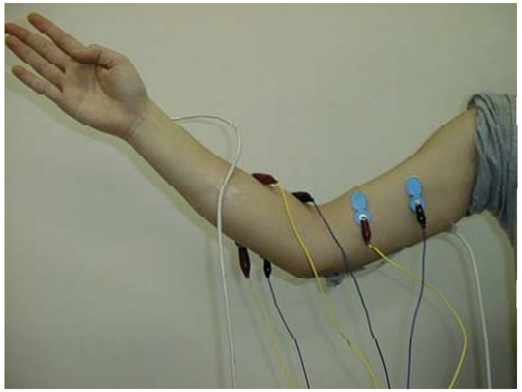
県内のFES患者約三十人のうち、歩行ロボットの使用に適している人は十人程度いるという。

秋田大の研究グループが開発した歩行ロボット（県工業技術センターで）

Dec. 1999

From medical technology to engineering





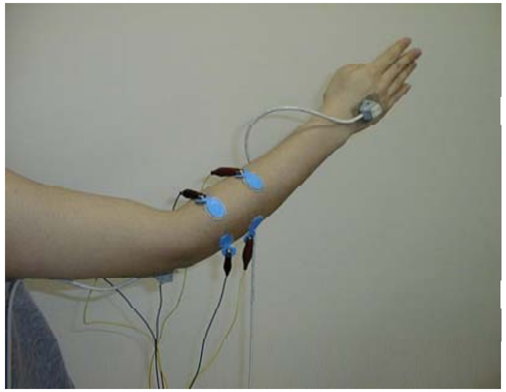
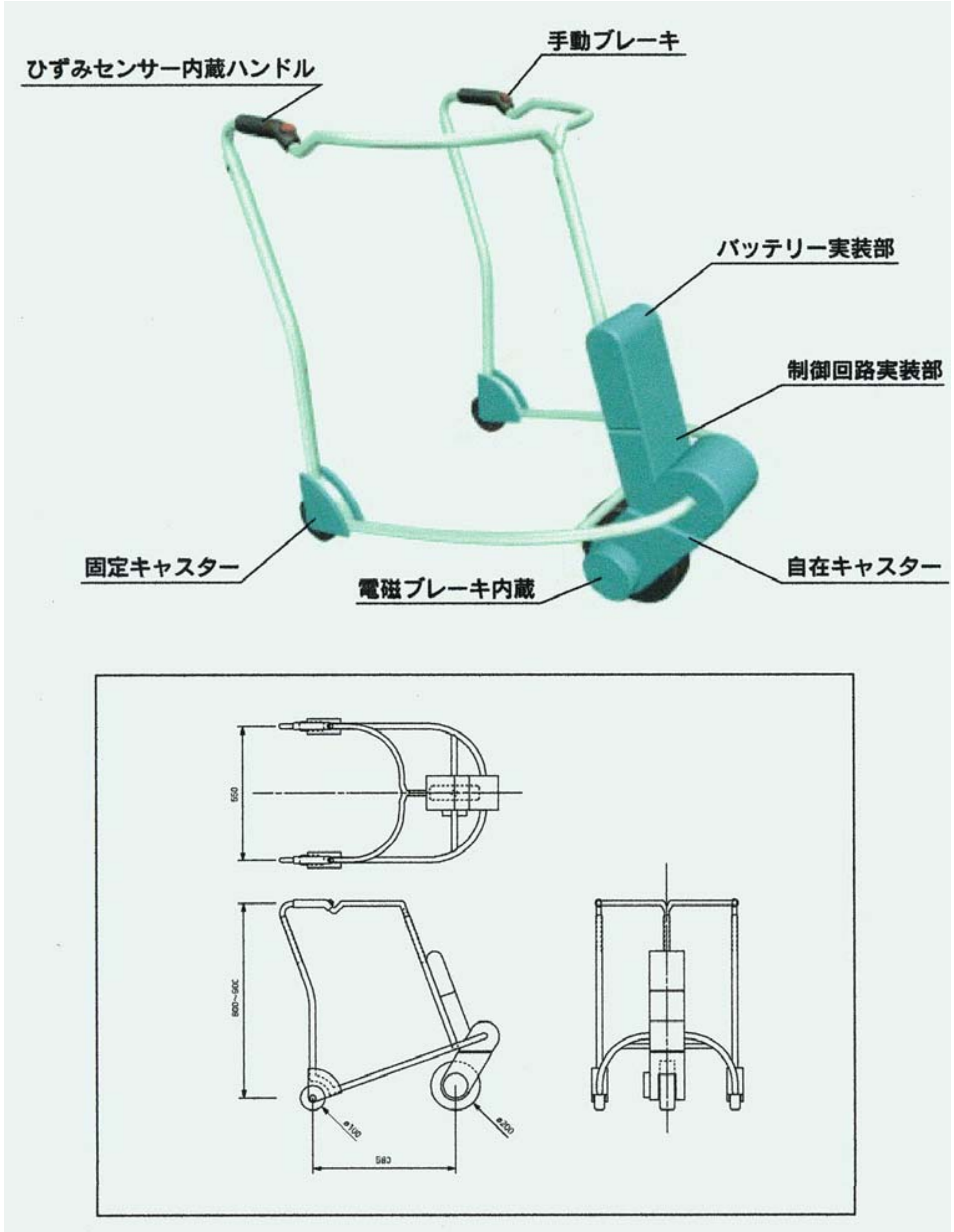


Image of commercial version

Automatic following

Support when it becomes necessary



Teleoperation of robot by gesture interface

Progression in robotics Fields with robots

- Sensor, Actuator, Digital controller, Mechanical systems
- Information technology, Internet, Home information appliances
- Buildings, Robots in home, Internet
- Assistive technology, Training, ***Rehabilitation***
- Transportation
- Infrastructure in city

Human friendly and assistive robots

- Level of robot elements becomes practical now.
- Cost reduction is required for elderly society of Japan.
- Innovation is expected by evolving the strong point of Japanese industry
- New technologies are expected for coping with difficult problems which come from elderly society.

Development of cooperative and assistive robots

- Market of robots not in industrial field
- Robots act friendly with human
- Robots can be operated by non-experts
- Researches on robotics may provide hints for understanding human function of brain

Development of cooperative and assistive robots

- Service robots and care robots
- Smart houses and robots, which are used for elderly people and disabled instead of care dogs
- Wearable robots, which are alternatives or compensations of human functions
- Communication aides, artificial legs with intelligence

Robot system for supporting ADL of elderly people which live alone

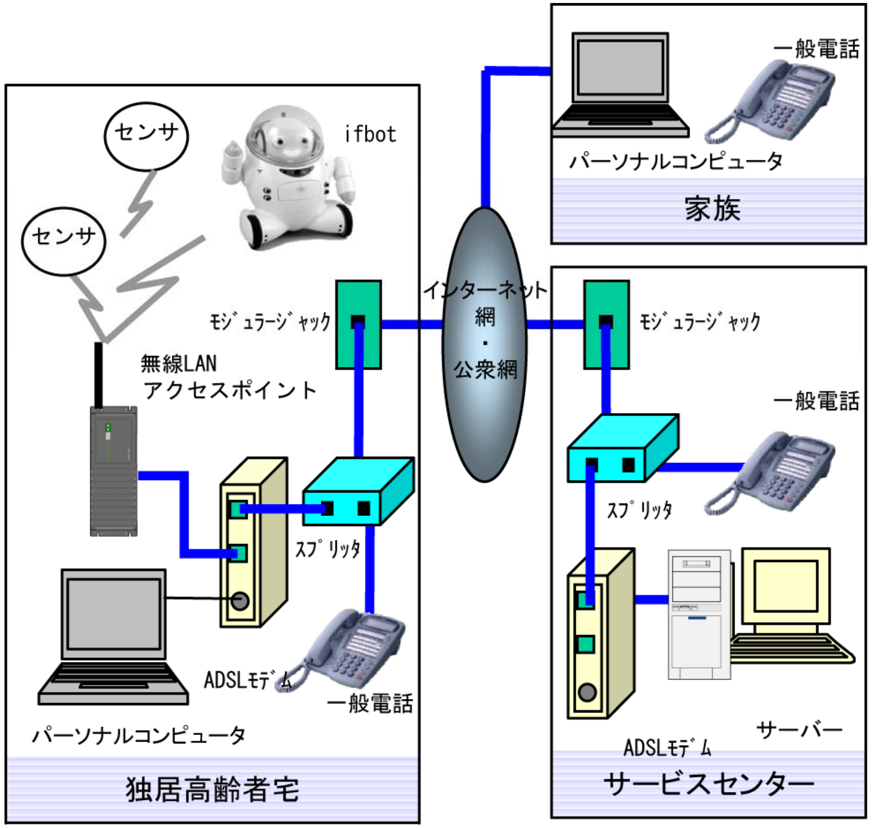
◆ Background

Compensations for communications with their families, for movement functions of ADL, for monitoring the health are required.

◆ Purpose

To construct a system for supporting elderly people, we use internet and robots. The system can provide several functions, for examples, to keep their safety from cheaters, or to monitor their health, or to enhance their communications with their family

The system developed



The internet system

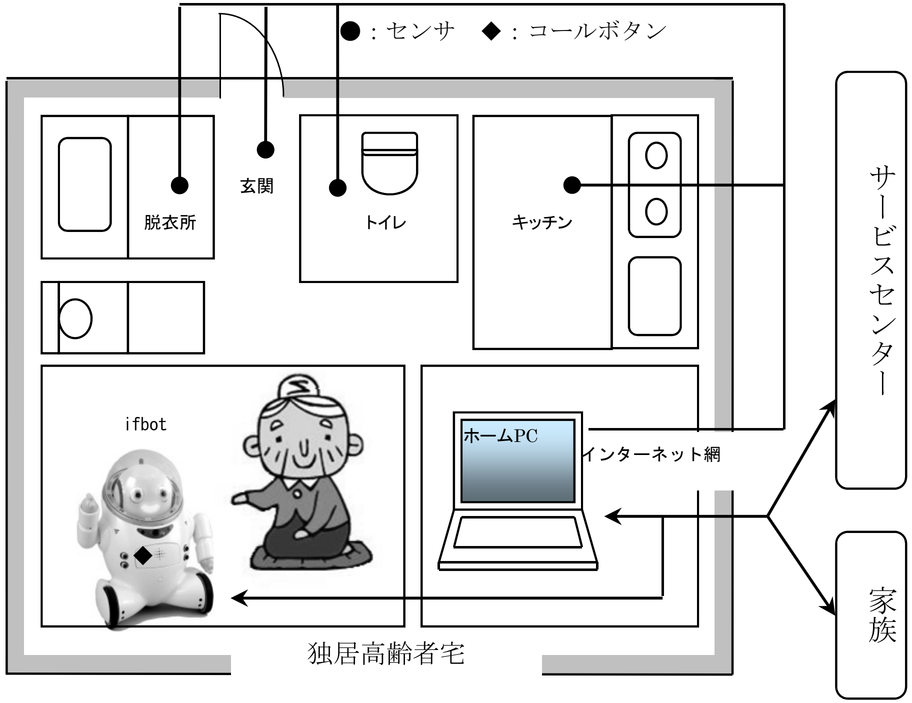


Illustration of the system

Further researches on assistive robots

- Safety
- Human friendly
- Human-machine interfaces
- Assists on human brain functions

Assist for human movements based on human functions

- ***Special problems for human in mammals***
- Model-based approach for designing assistive devices
- Raw power of Japanese robots

Relation on consumption energy in mammals

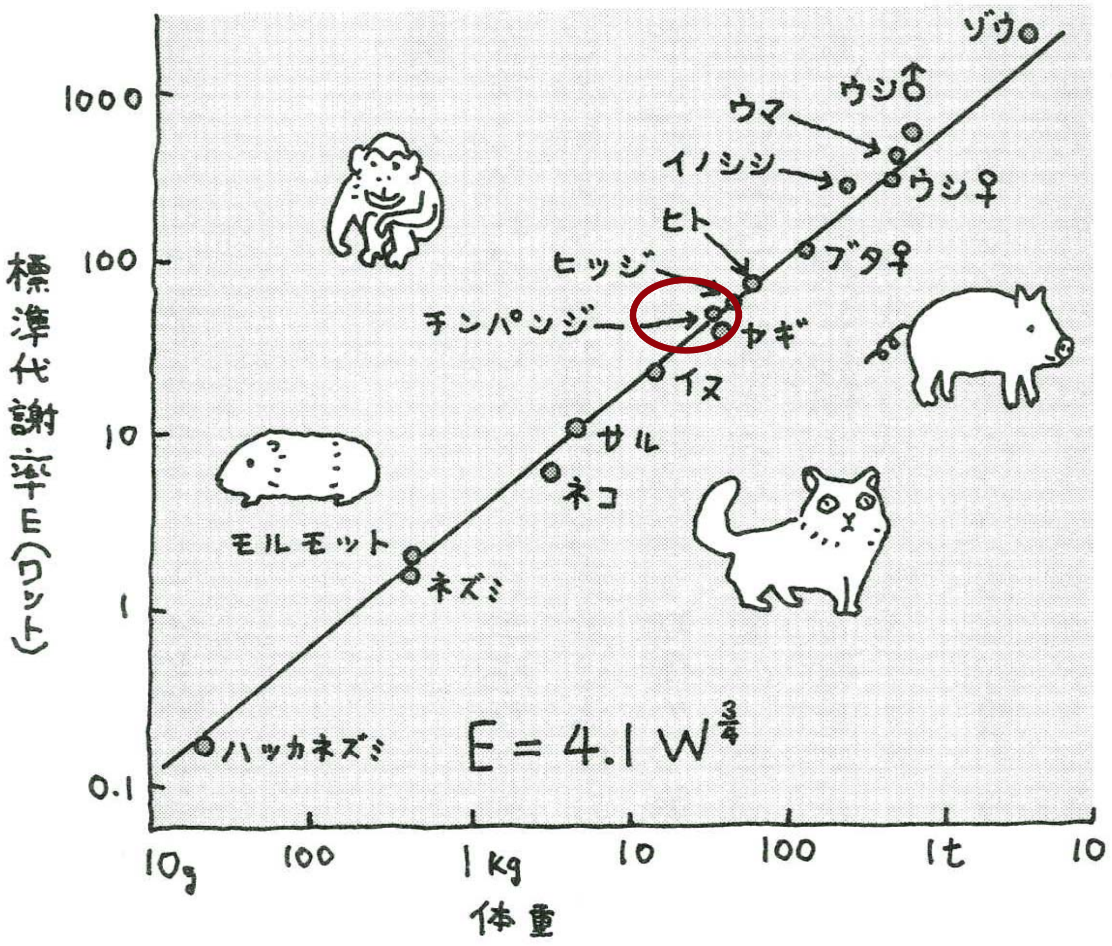


図5　エネルギー消費量と体重との関係の両対数グラフ
(Schmidt-Nielsen, 1984をもとに描く)

「時間」本川達雄
NHKライブラリー
1996

人は　73W
平均125W

人工的なエネルギー
を入れると
2.75kW　(40倍)

Upper bounds of human power

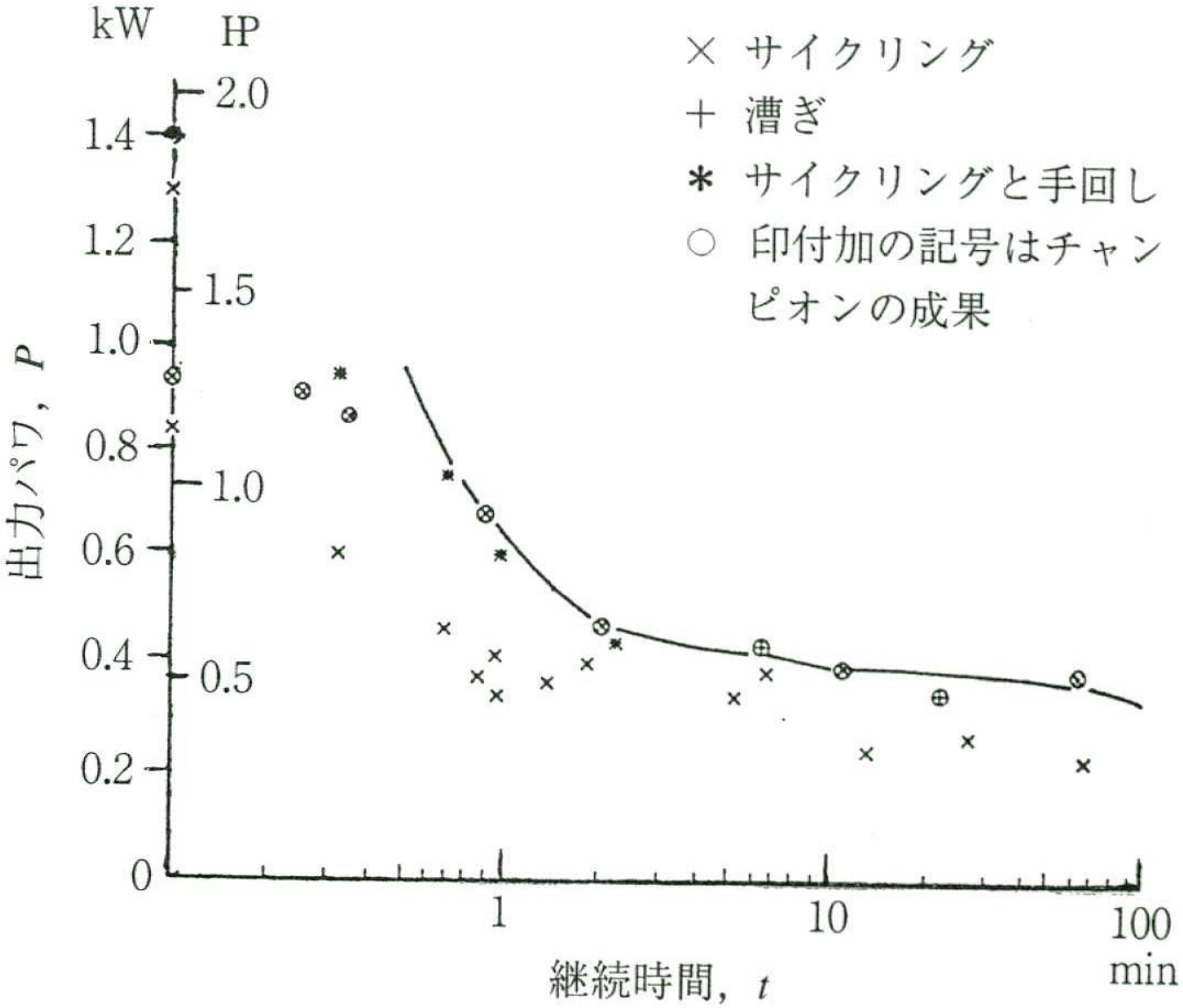


図 **6.2-12**　ヒトの出力と時間との関係（Sherwin, 1975）

Assist for human movements based on human functions

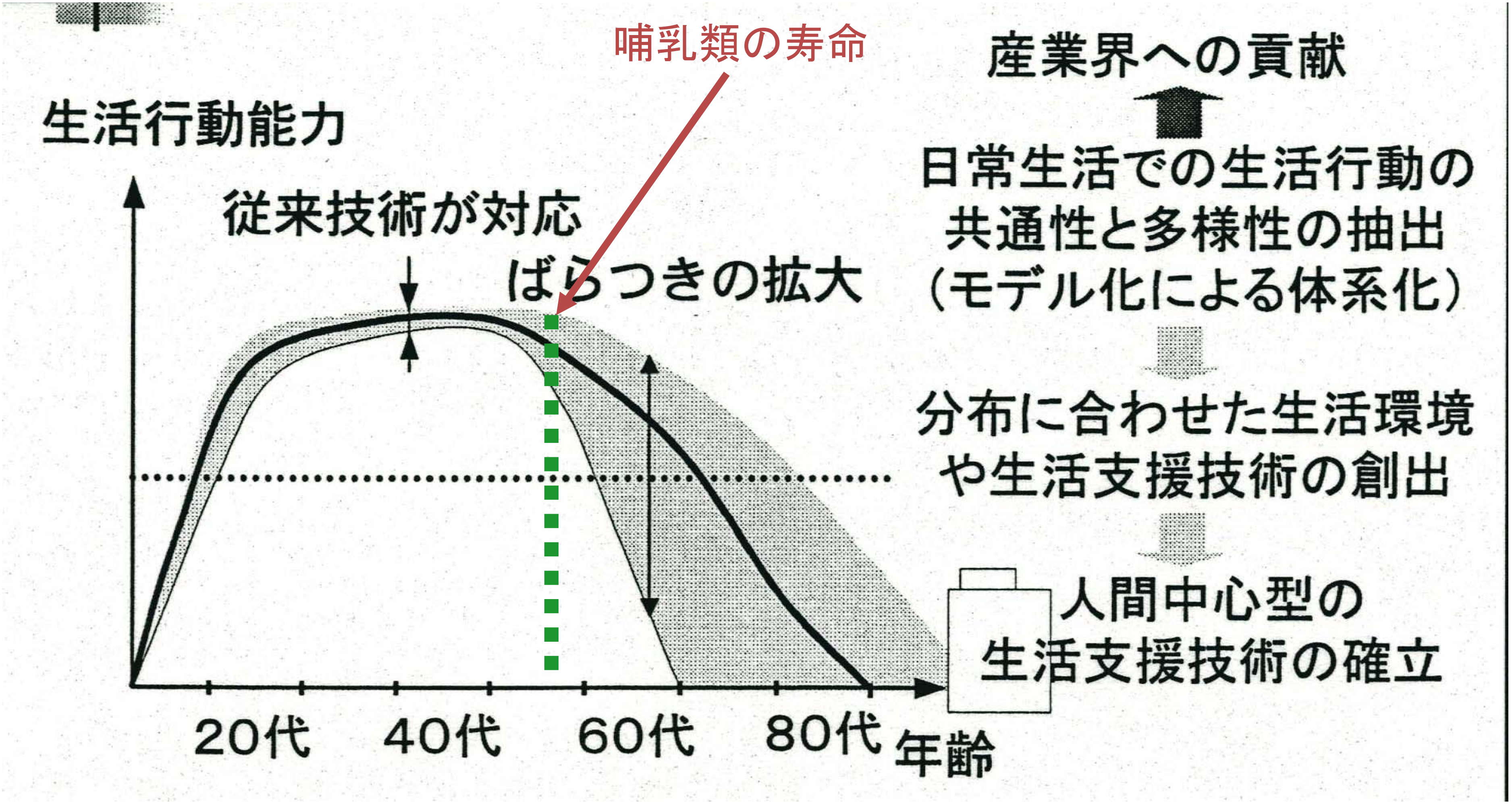
- Special problems for human in mammals
- ***Model-based approach for designing assistive devices***
- Raw power of Japanese robots

People over 75 years old will be at work in Japan

- **Solution to this problem**

- Training with some devices
- Wearable devices to compensate vanished functions
- Several setups in daily lives
- Barrier free design of infrastructures

Larger variance of functions in elderly people



Required methods

- Finding the needs

- Data base for the functions

- Opening the problems

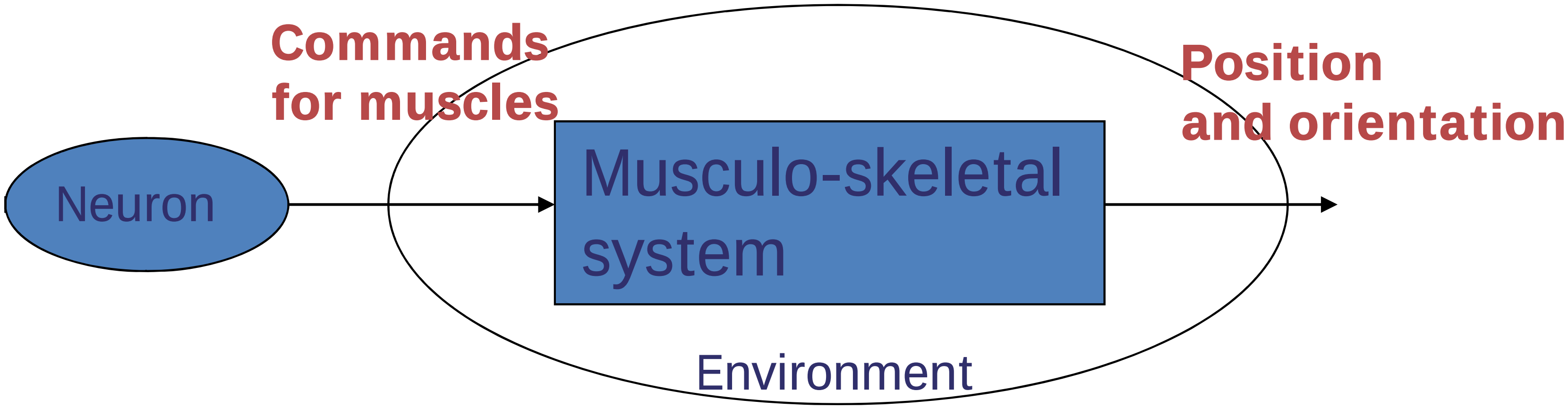
Model-based approaches will be useful to solve these problems

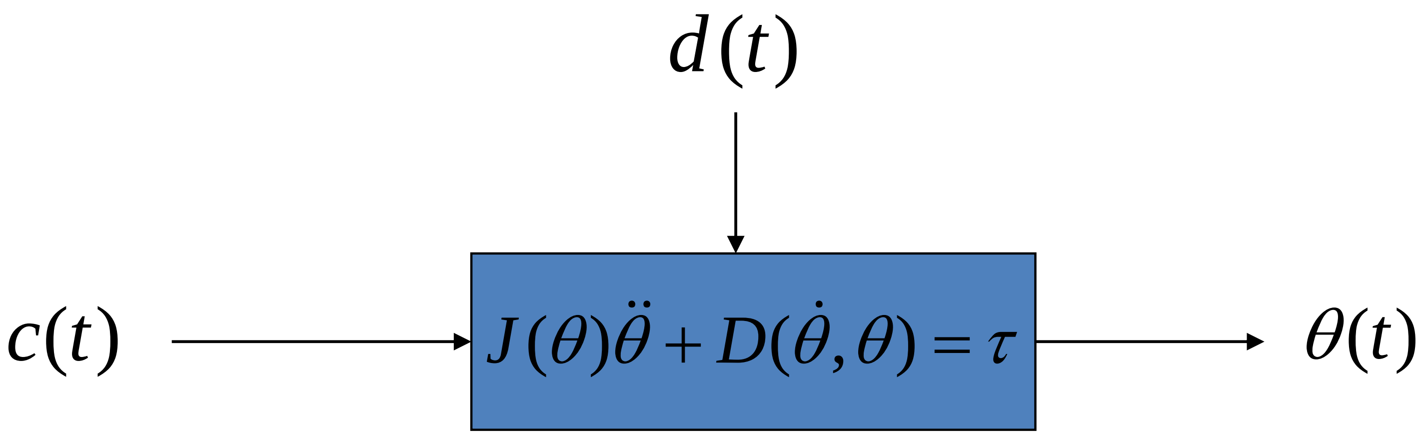
Model-based approach for analyzing human movements

- **What can we do with models?**
- **Method for identifying models**
- Analysis of human movements: Wheel chair propulsion and determining the optimal form
- Simulation of bipedal walking and its application for designing artificial legs
- Concluding remarks

What is model?

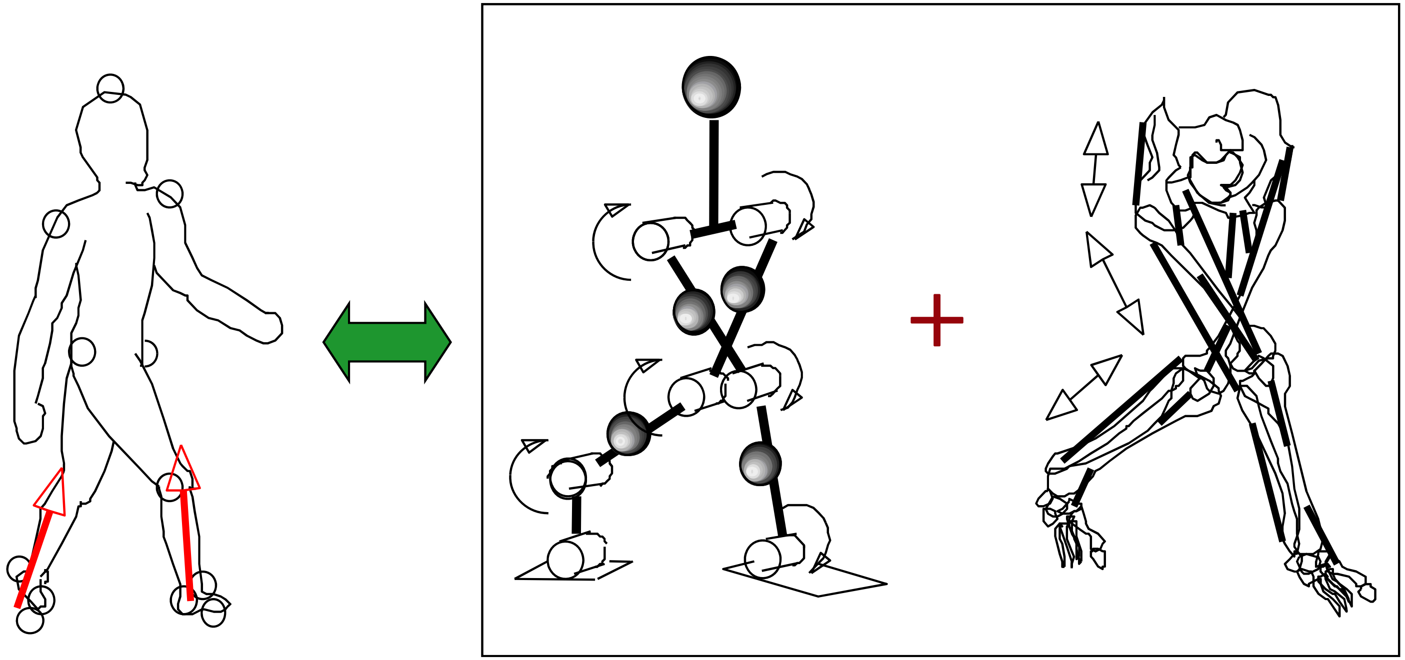
Mathematical models





Mathematical model (equation of motion)

Model and the equation of motion



Human body

Rigid link model

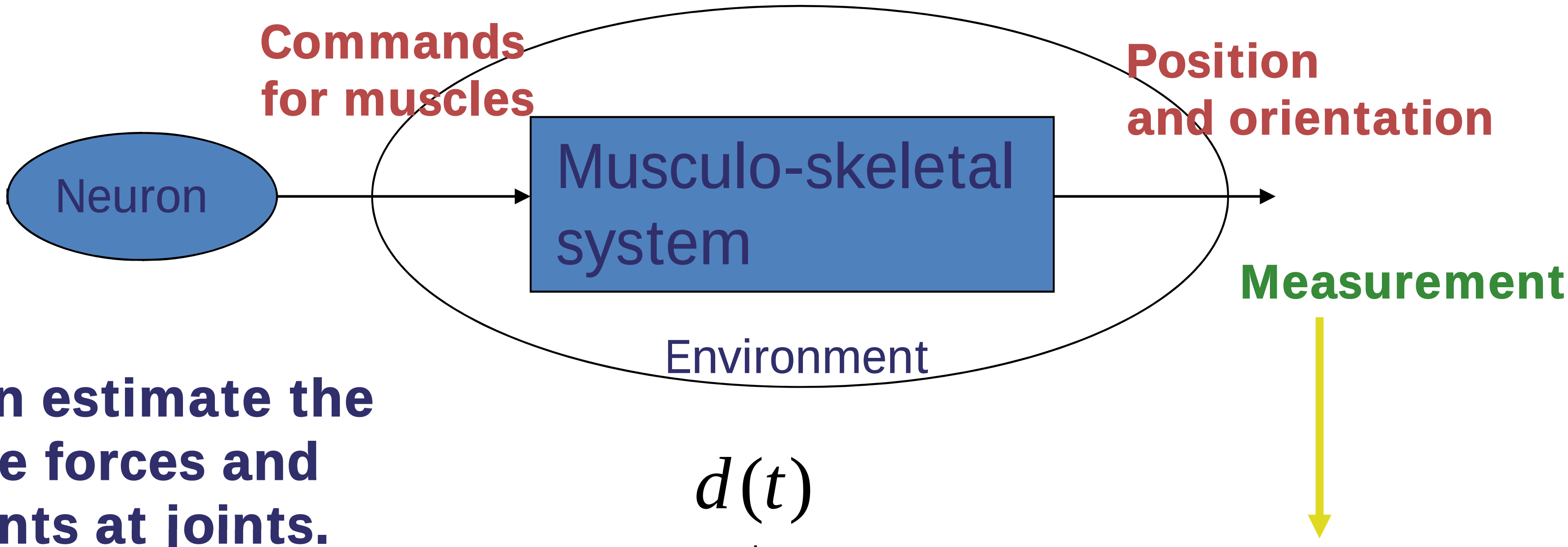
The corresponding equation of motion

Musculo-skeletal model

The actuator like string

How to use model Ⅰ

Inverse dynamics



We can estimate the passive forces and moments at joints.

Non-invasive measurment

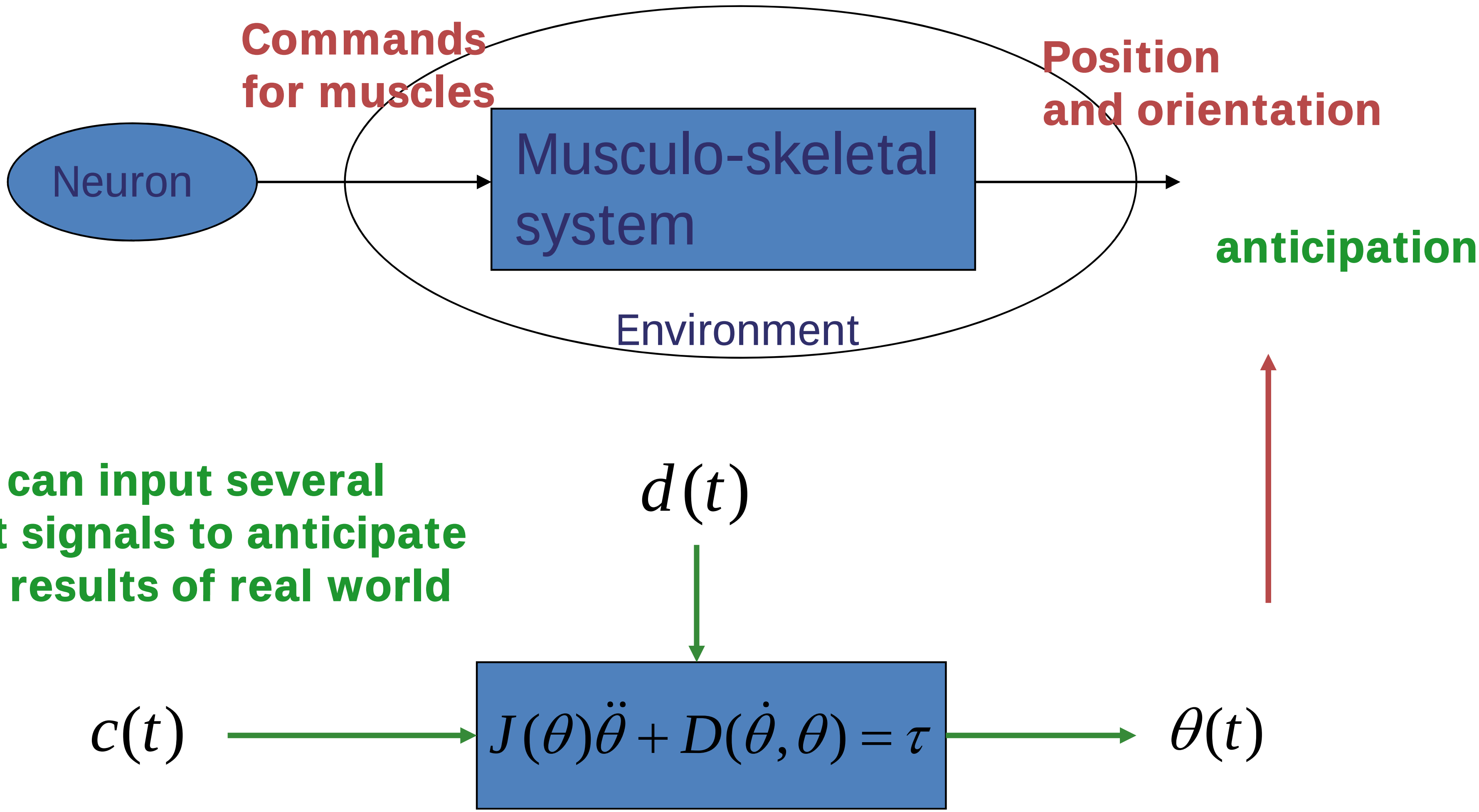
$$d(t)$$

$$c(t) \leftarrow J(\theta)\ddot{\theta} + D(\dot{\theta}, \theta) = \tau \leftarrow \theta(t)$$

We have all values of state variables in the model.

How to use model II

forward dynamics Anticipation for real world **before** the event

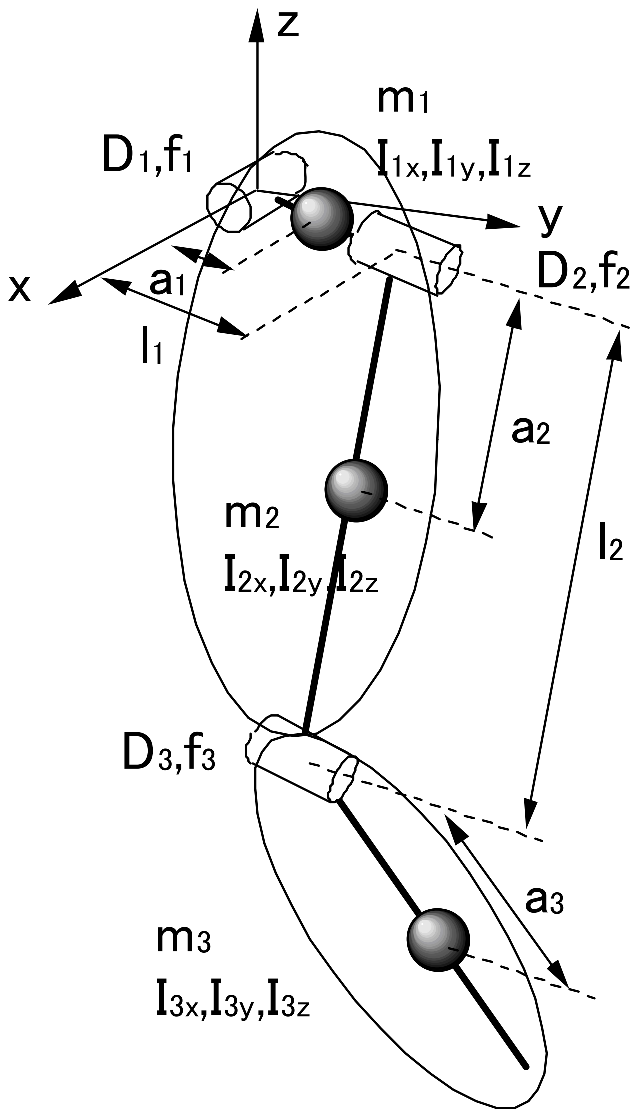


We can input several test signals to anticipate the results of real world

Mathematical model

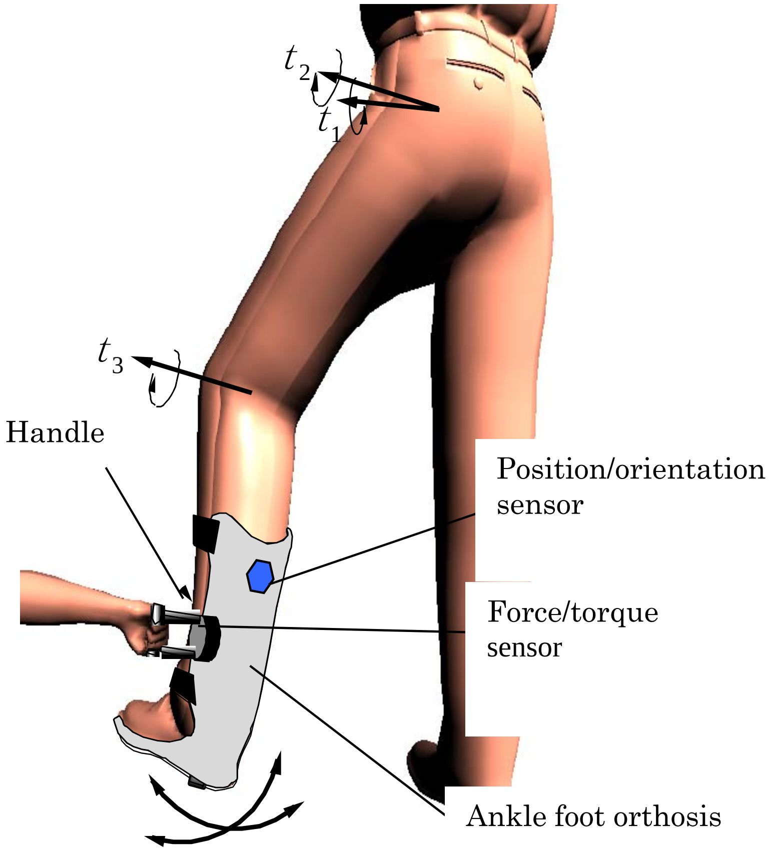
Link Model for lower limb

The dynamics of the person is required for the simulations



mass	m[kg]
Link length	l [m]
Position of Cg	a [m]
Moment ofinertia	I_x[kgm2]
	I_y[kgm2]
	I_z[kgm2]
viscosity	D[Nms/rad]
Coulomb friction	f [Nm]

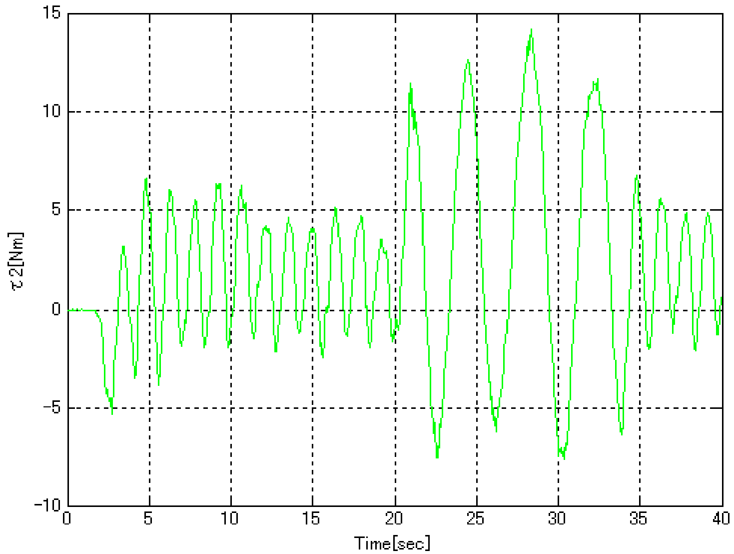
Experimental setup



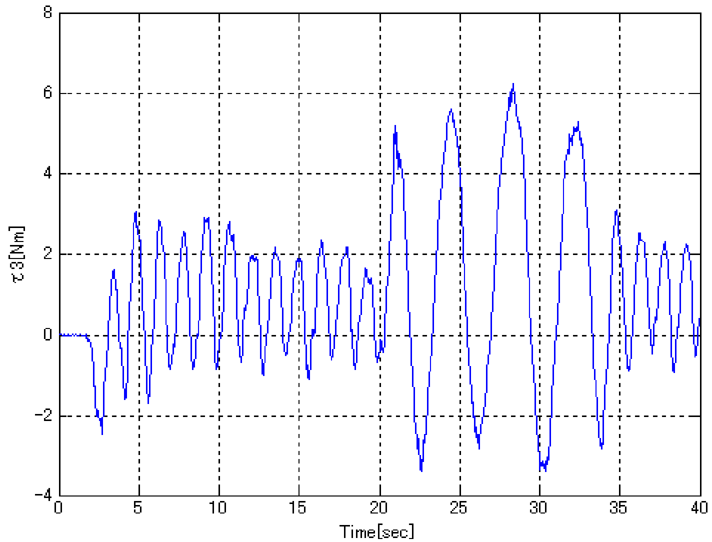
Passive motion is generated by inputting force and moment through the handle.

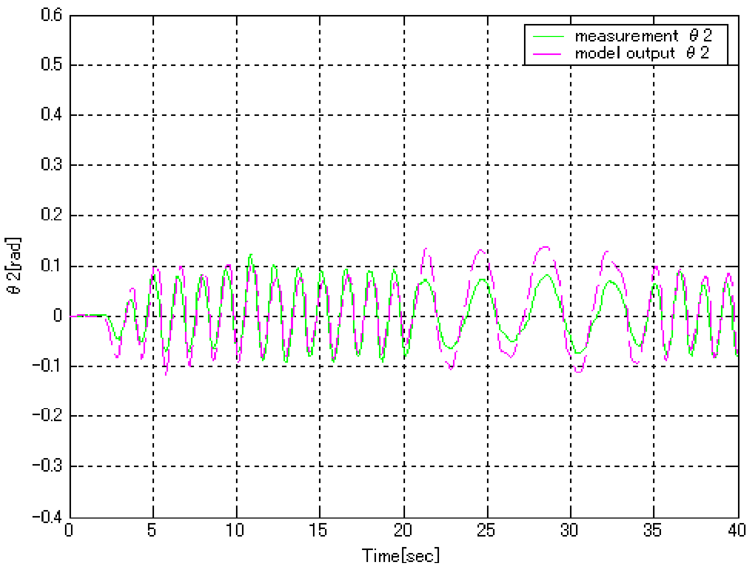
Angles of the joints and the applied force and moment are measured by sensors.

Result - two degree-of-freedom -

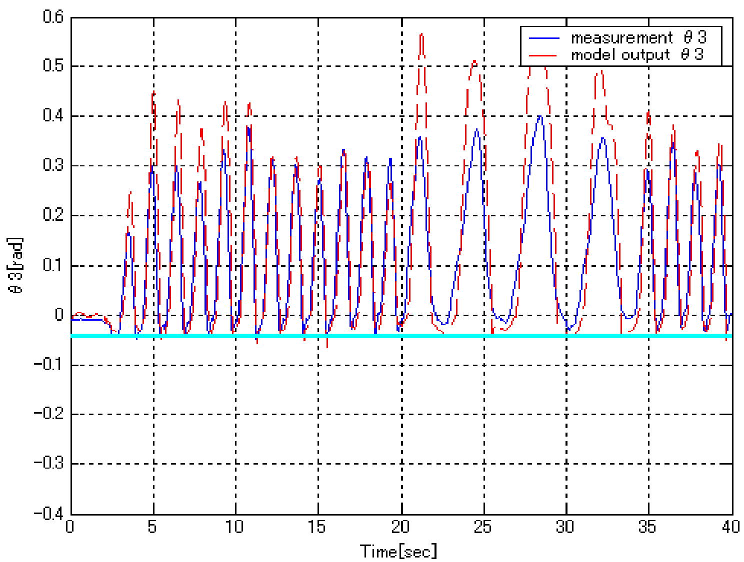


torques





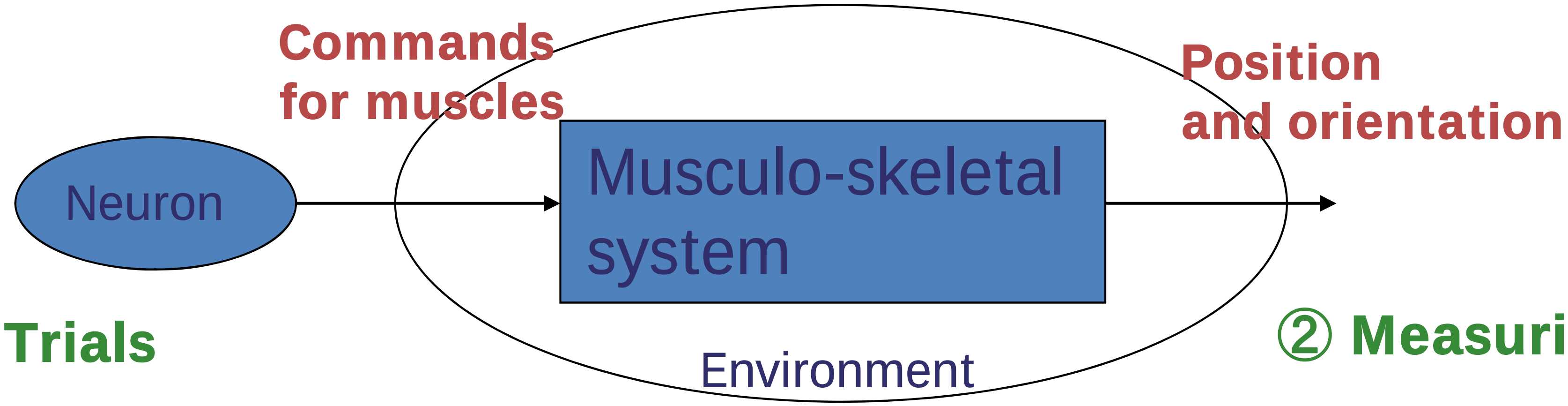
angles



Hip joint **Knee joint**

- What can we do with models?
- Method for identifying models
- **Analysis of human movements: Wheel chair propulsion and determining the optimal form**
- Simulation of bipedal walking and its application for designing artificial legs
- Concluding remarks

We can use the two methods successively



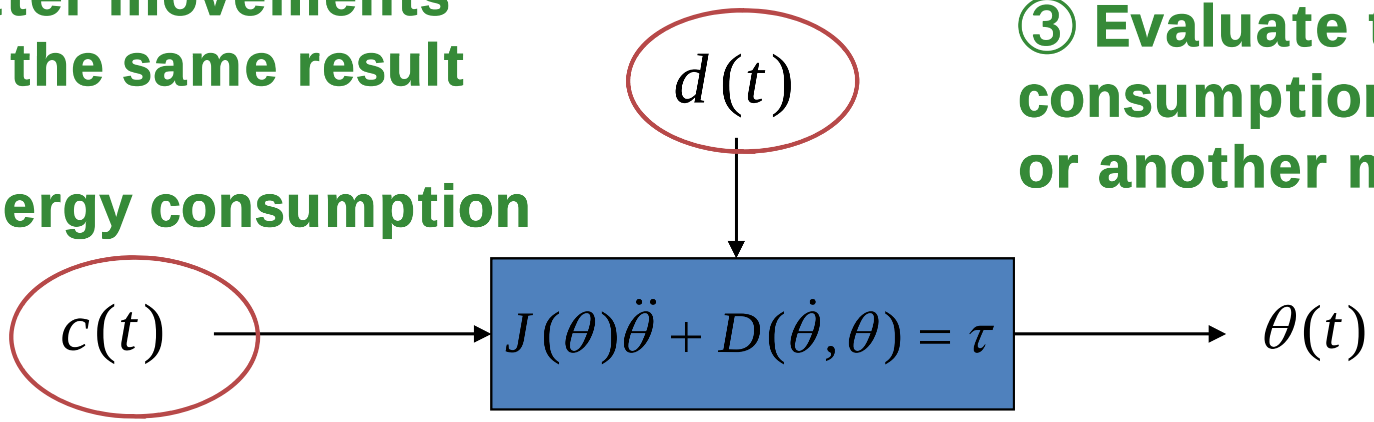
① Trials

② Measuring

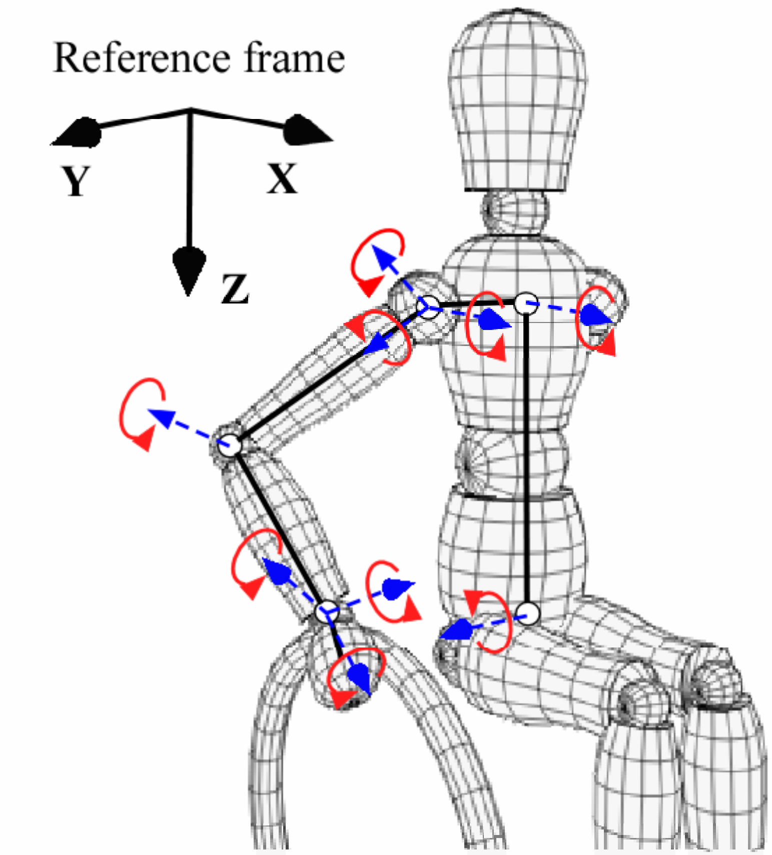
④ Find better movements to achieve the same result

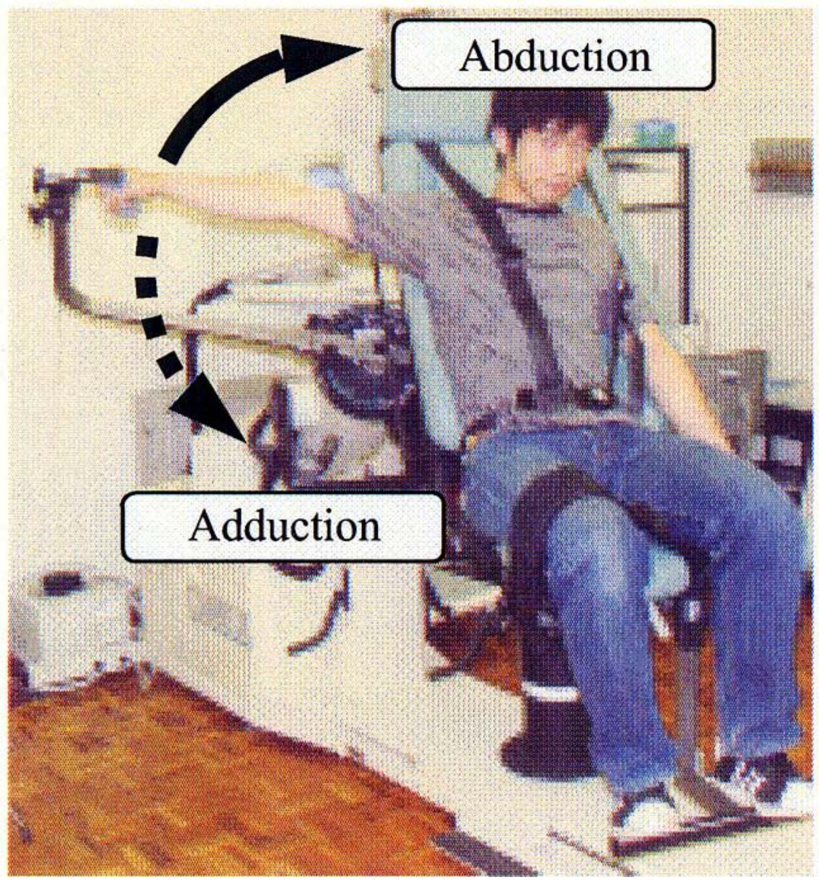
Smaller energy consumption

③ Evaluate the consumption energy or another measures



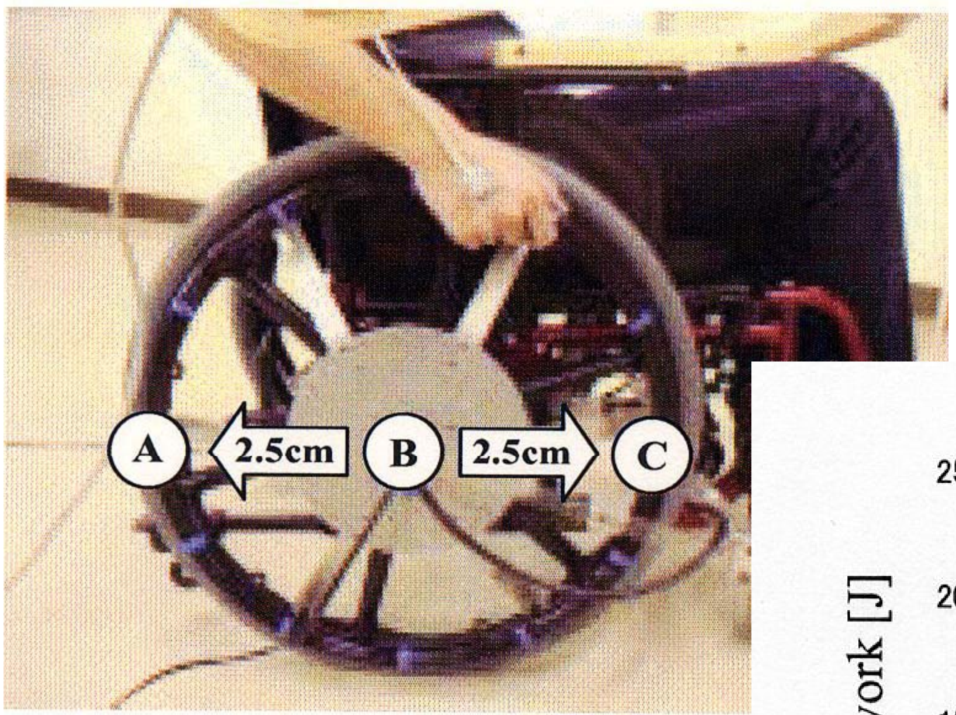
Physical modeling and evaluate the maximum generated moments of the joints

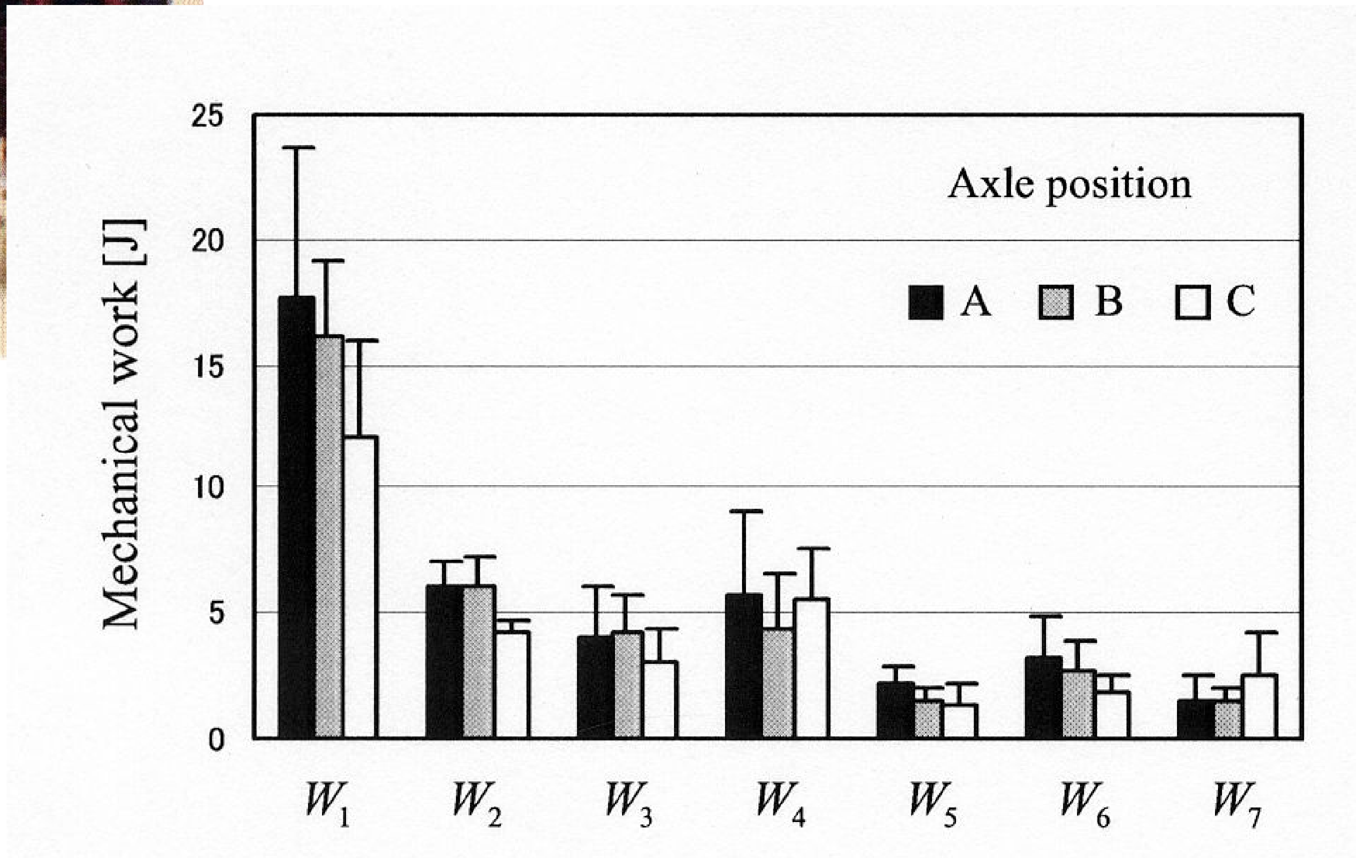




9 degree-of-freedom model

For an example: the difference energy consumption with the difference position of wheels





Performance criterion

Mechanical energy to obtain unit distance of sift

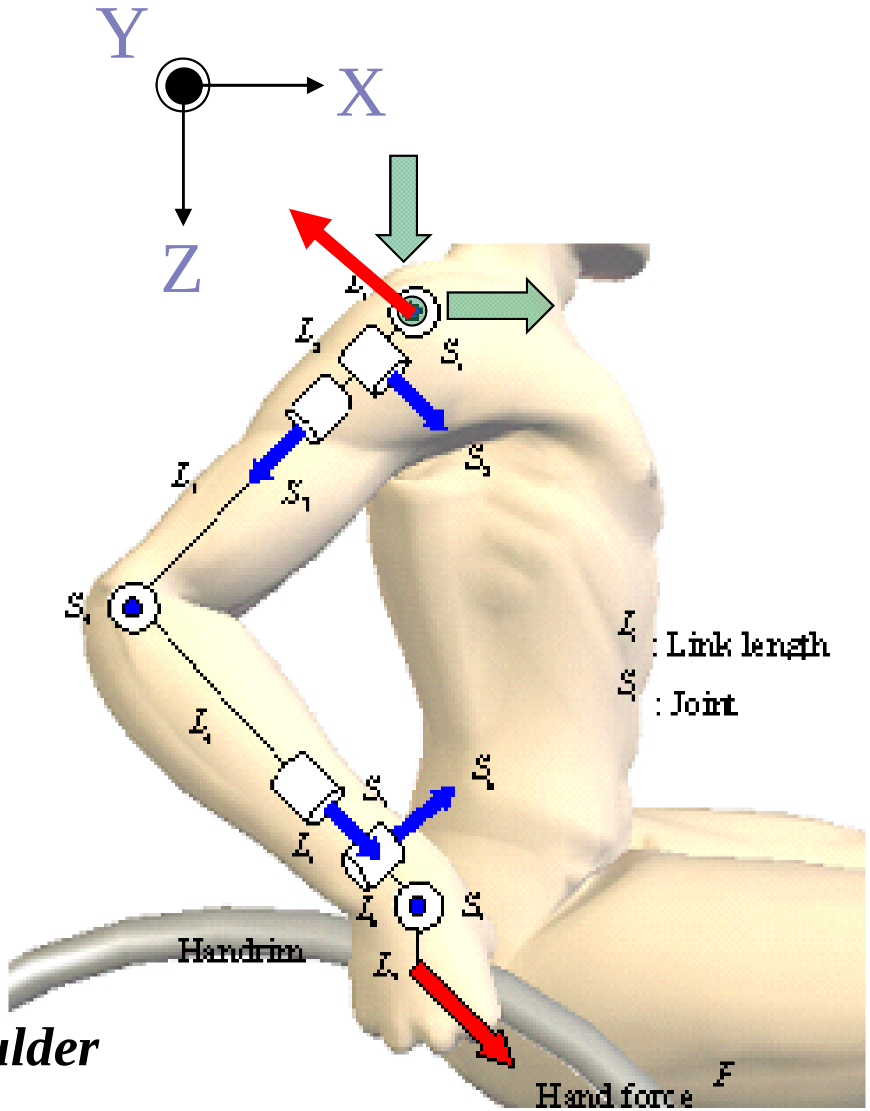
$$\boldsymbol{J} = \sum_{i}^{7} \int_{ts}^{tf} \left| \tau_i \ \dot{\theta}_i \right| dt + \int_{ts}^{tf} \left| \boldsymbol{F} \dot{\boldsymbol{T}}_b \right| dt$$

$\theta \in R^{7\times1}$:*vector of joint angle*

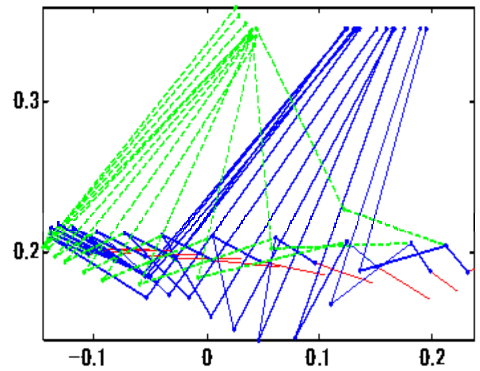
$\tau \in R^{7\times1}$:*vector of joint tirque*

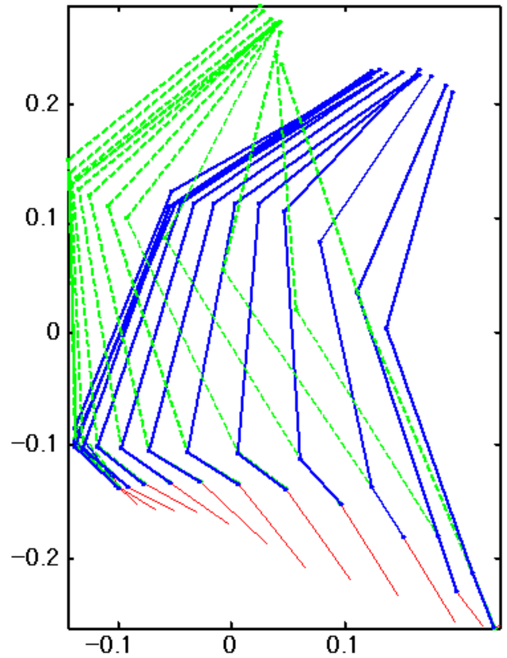
$\boldsymbol{T}_b = [\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}]^T \in \boldsymbol{R}^{3\times1}$:***displacement of soulder***

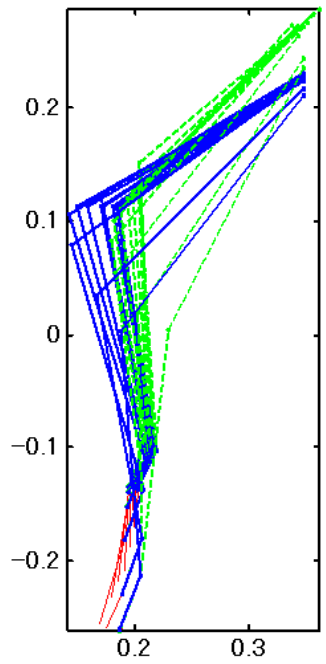
$\boldsymbol{F} = [\boldsymbol{Fx}, \boldsymbol{Fy}, \boldsymbol{Fz}] \in \boldsymbol{R}^{3\times1}$:***reaction force at shoulder***



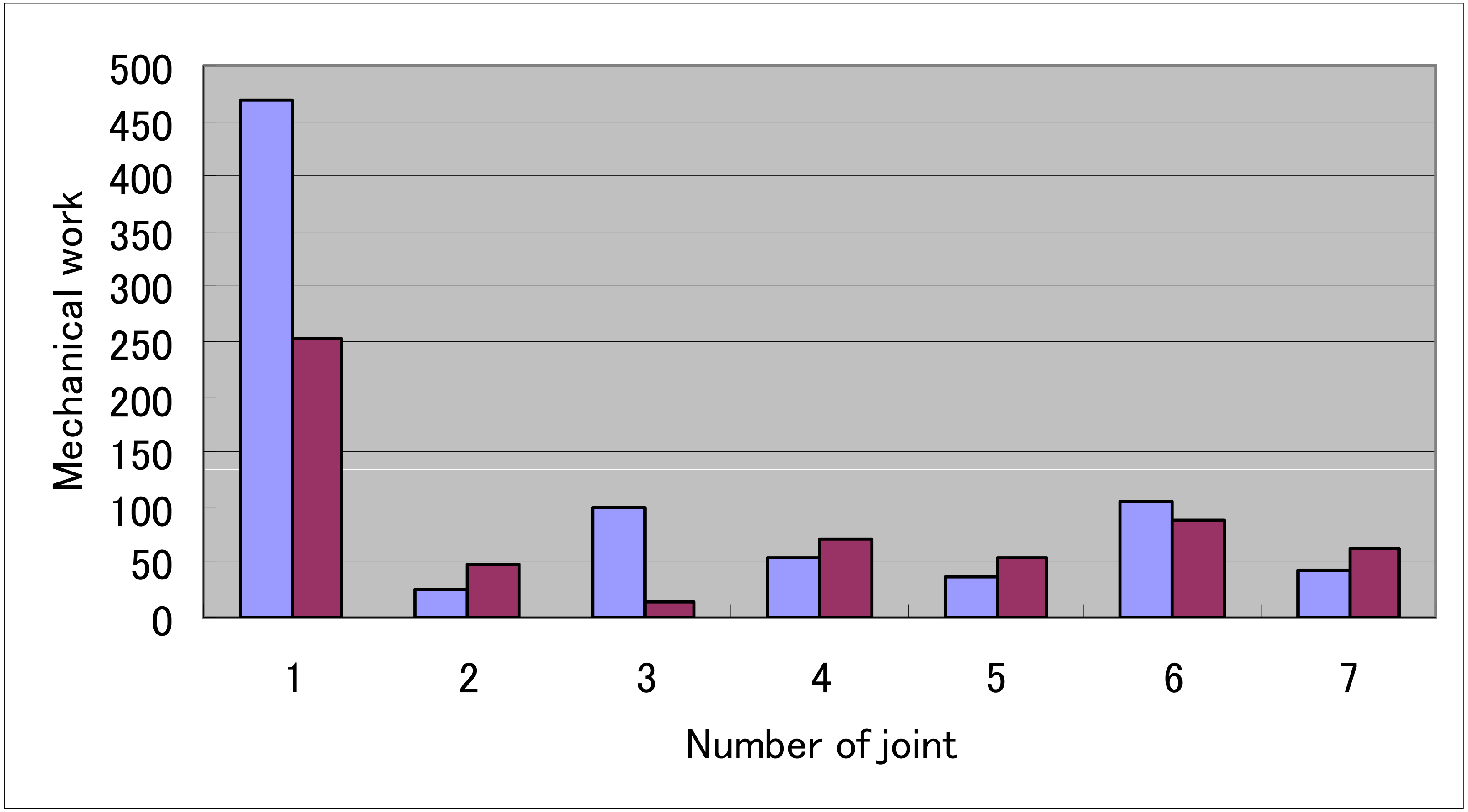
Calculation for smaller energy consumption by GA





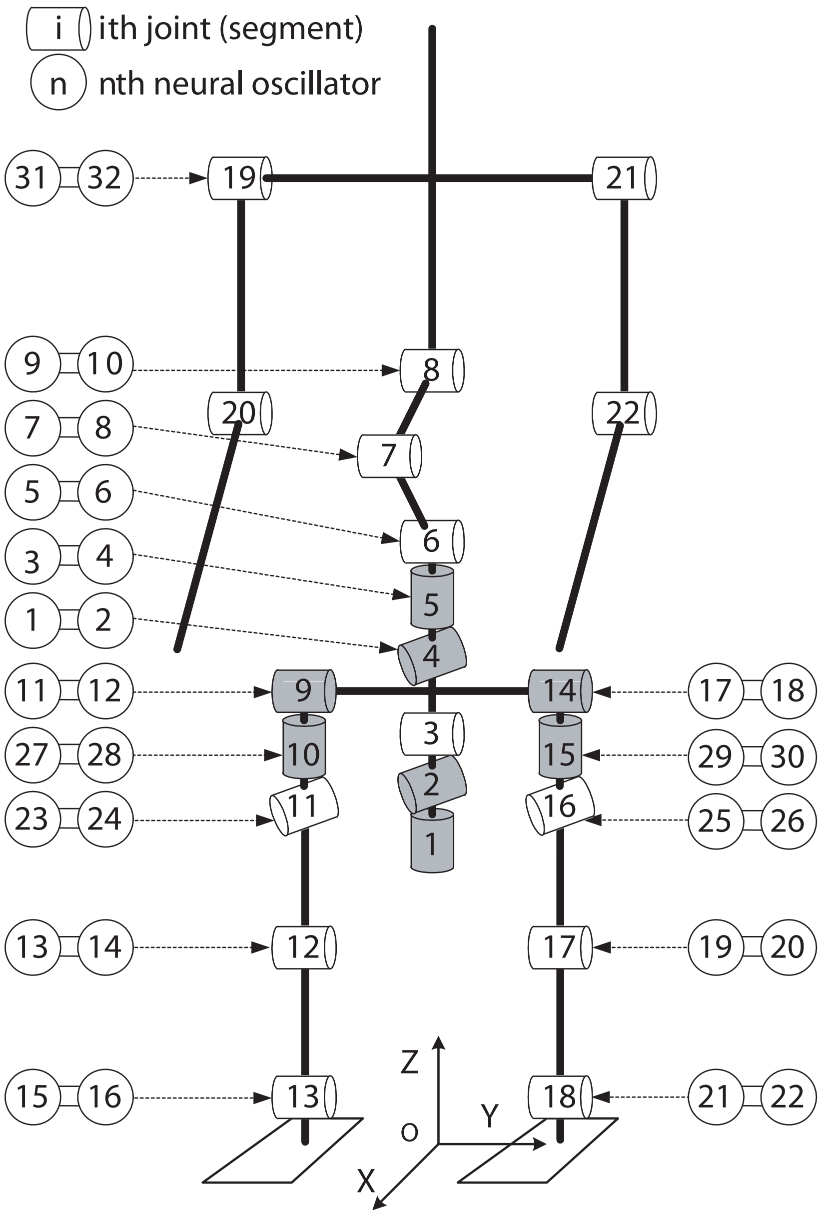


Reduction of the consumption energy



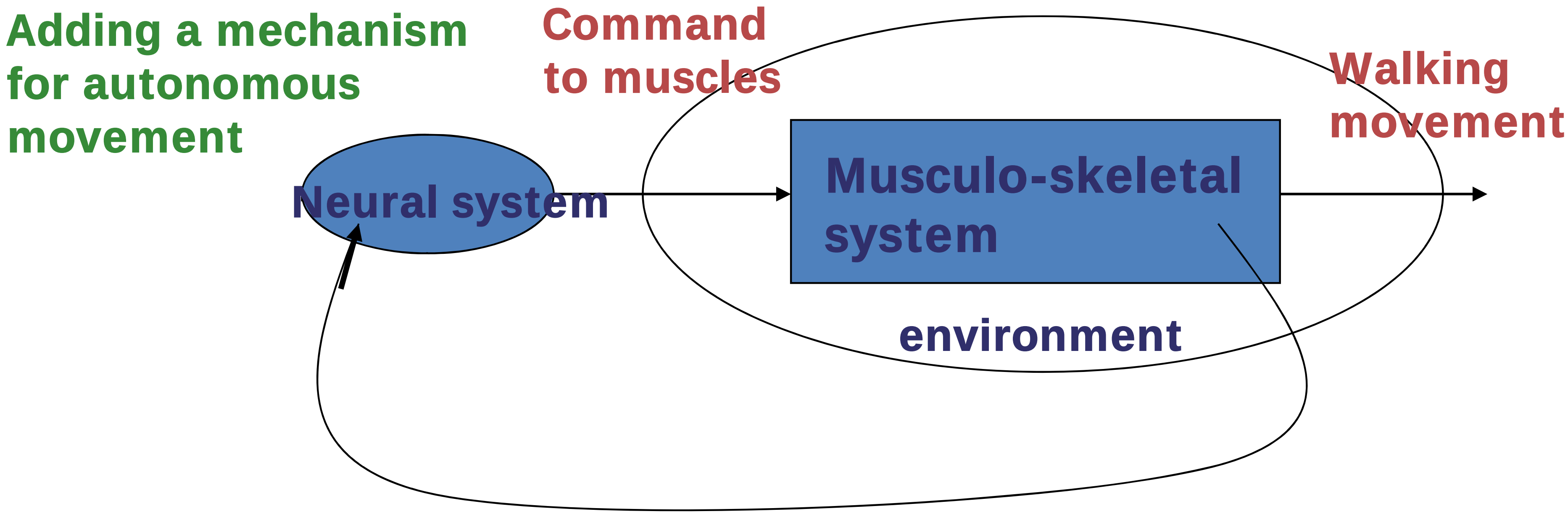
- What can we do with models?
- Method for identifying models
- Analysis of human movements: Wheel chair propulsion and determining the optimal form
- **Simulation of bipedal walking and its application for designing artificial legs**
- Concluding remarks

3 dimentional musuculo-skeletal model



With my colleague: prof. K. Hase

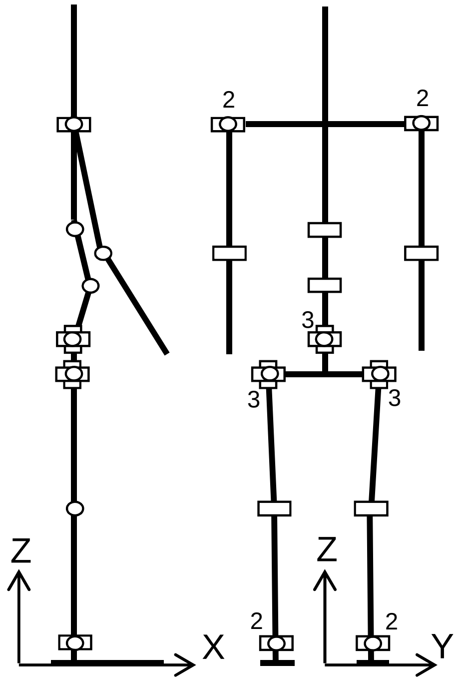
Automatic generation of walking - walking simulation -



Adding feedback pass from position and orientation

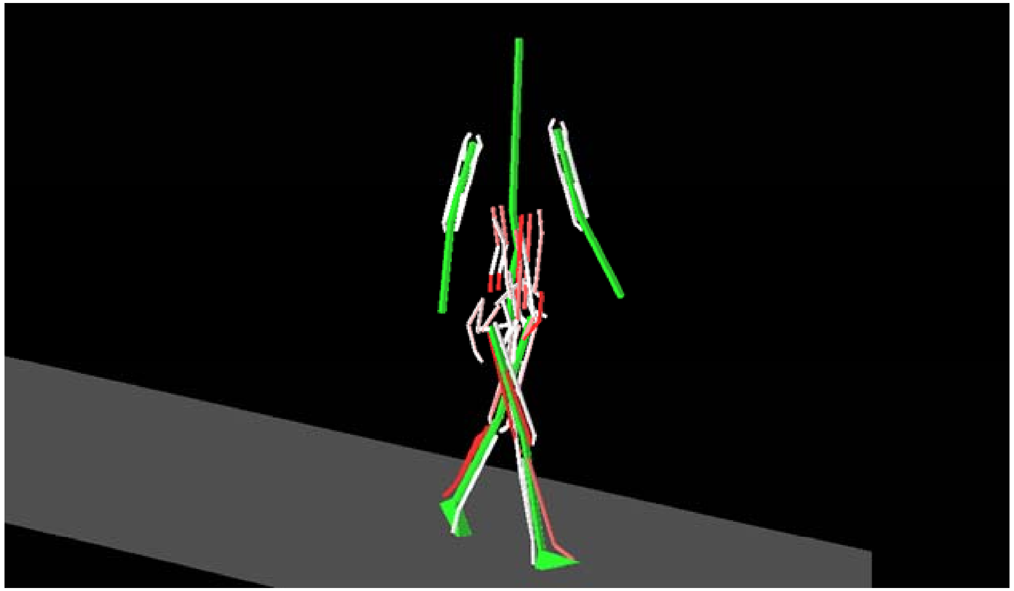
Taga, 2 dimenstional, central pattern generator, entrainment dynamics

Simulation of walking



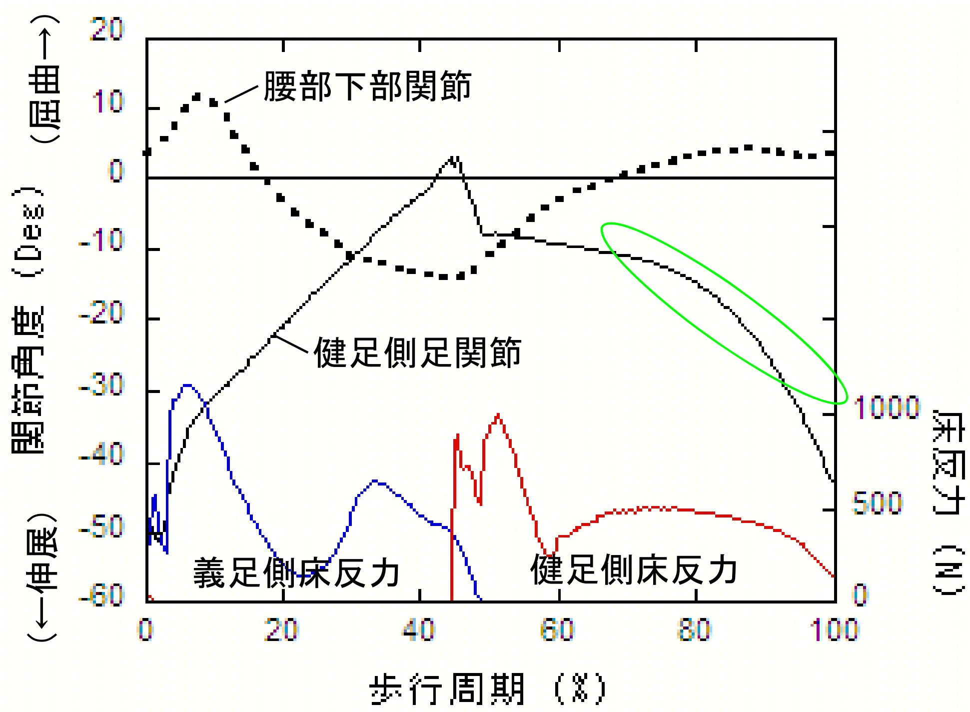
14 rigid links
23 joints
70 muscles
23 CPG

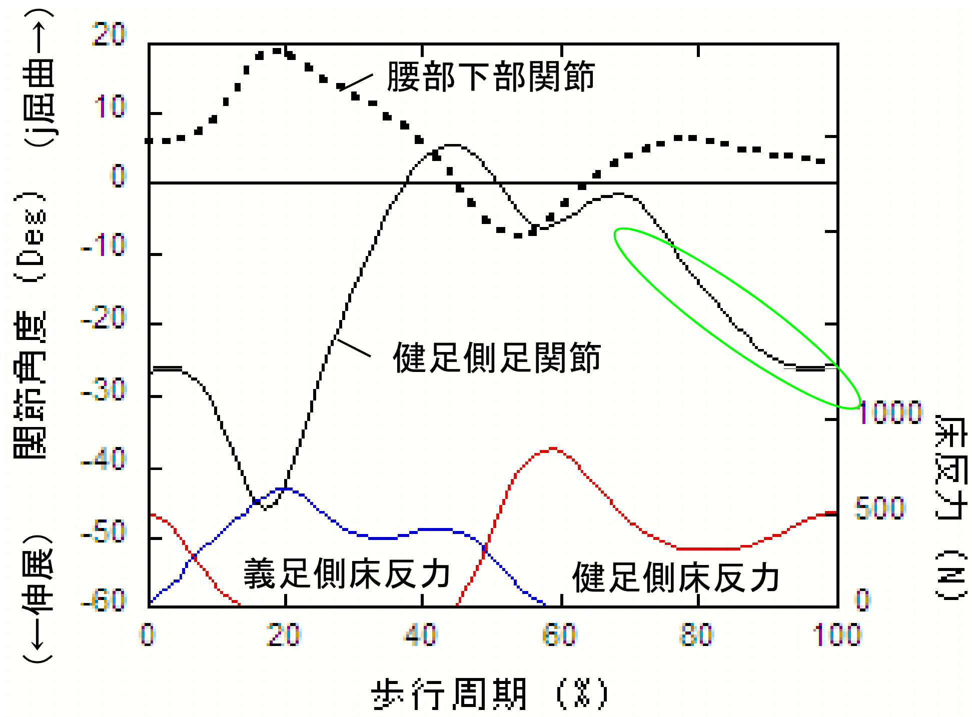
Numerical search with GA



Prof. Kazunori Hase

Comparison with the experiment





Walking speed 1.28m/sec
Average period 0.96sec

Walking speed 1.33m/sec
Average period 1.11sec

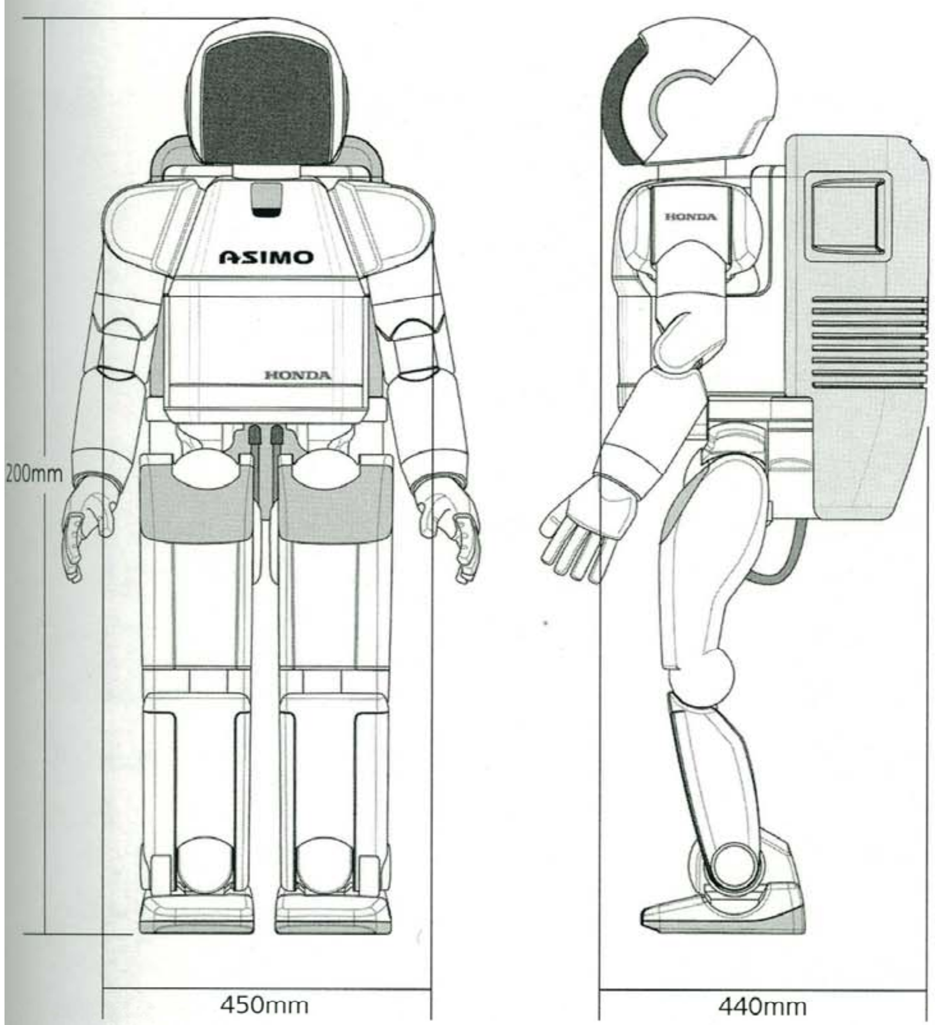
simulation **experiment**

Remarks

- Model based approach for designing assistive devices for disabled and elderly persons has been presented.
- It has been shown that we can design the assistive device for a particular person based on modeling the dynamics and the appropriate quantitative evaluation.
- The preciseness of our analysis and the practical design are targets of further researches. The design tool on computer for such devices will be required.

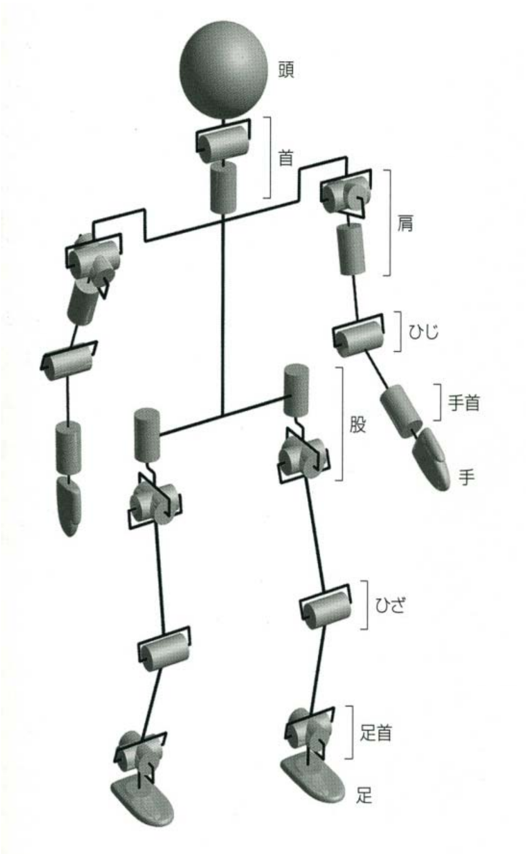
Assist for human movements based on human functions

- Special problems for human in mammals
- Model-based approach for designing assistive devices
- ***Raw power of Japanese robots***



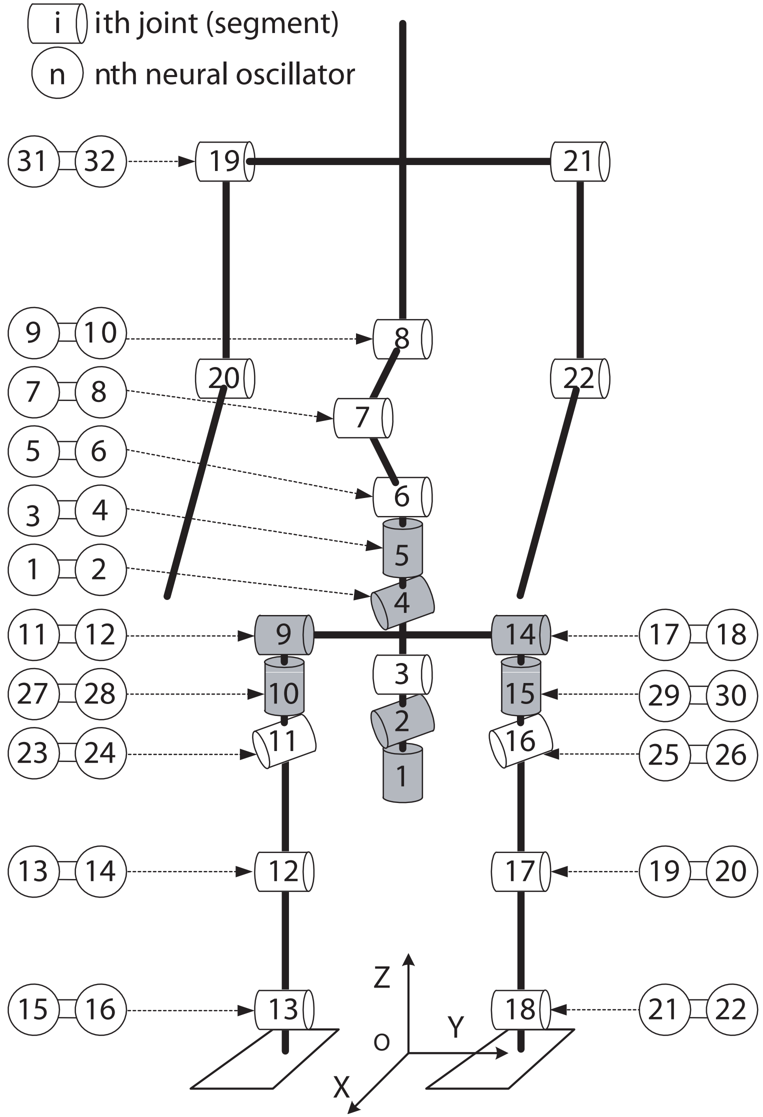
スペック		
寸法		身長1200mm、幅450mm、厚み440mm
体重		43kg
歩行速度		0〜1.6km/h
歩行周期		周期可変、歩幅可変
把持力		0.5kg/hand（5指ハンド）
アクチュエーター		サーボモーター＋ハーモニック減速機＋駆動ユニット
制御部		歩行･運動制御ユニット、ワイヤレス通信ユニット
センサー	足部	6軸力センサー
	胴体部	ジャイロ･加速度センサー
電源部		38.4V/10AH（ニッケル水素電池）
操作部		ワークステーションおよび携帯コントローラー

Specifications of Asimo



自由度		
頭	首(上下方向/回転)	2自由度
腕	肩(前後方向/上下方向/腕の回転)	3自由度
	ひじ(前後方向)	1自由度
	手首(回転)	1自由度
		5自由度×2腕=10自由度
手	5指(把持=ものをつかむ動き)	1自由度
		1自由度×2本=2自由度
脚	股(前後方向/左右方向/旋回方向)	3自由度
	ひざ(前後方向)	1自由度
	足首(前後方向/左右方向)	2自由度
		6自由度×2脚=12自由度
合計		26自由度

Asimo



Our simulator

Humanoid（P3 from Honda）

weight: 100kg　payload: 2kg～10kg

velocity of walking: 0. 6m/s

power: 700W　30min/charge

[4W/kg～7W/kg]

Human

power: 80W～600W

[1. 3W/kg～10W/kg]

walking: 500W（2m/s, 60kg）

300W（1m/s, 60kg）

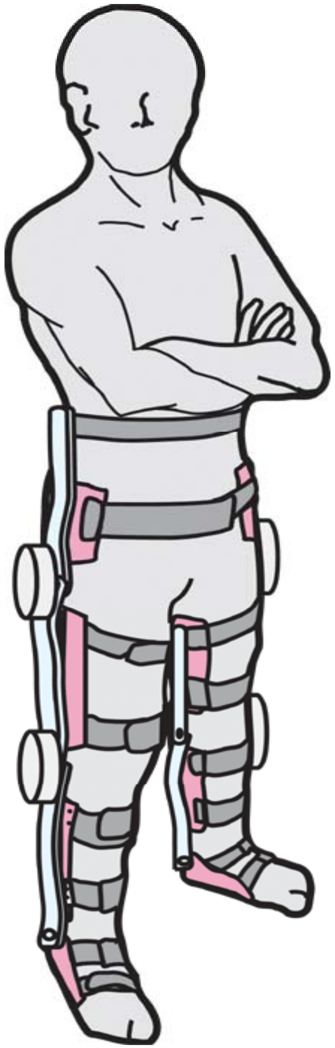
Assistive and rehabilitation robots for walking aid

- **background**

- paraplegia（5,000/year）
  by motor vehicle accident, et alia
- hemiplegia（70,000/year） by stroke
- life-style related diseases

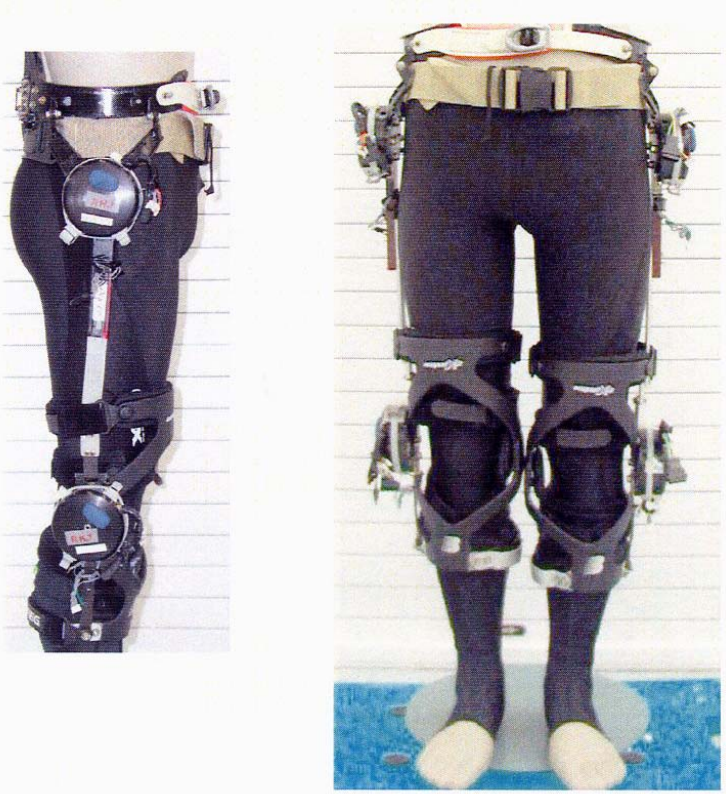
To solve these problems

- **research**
- develop assistive and rehabilitation robots preserving health and QOL



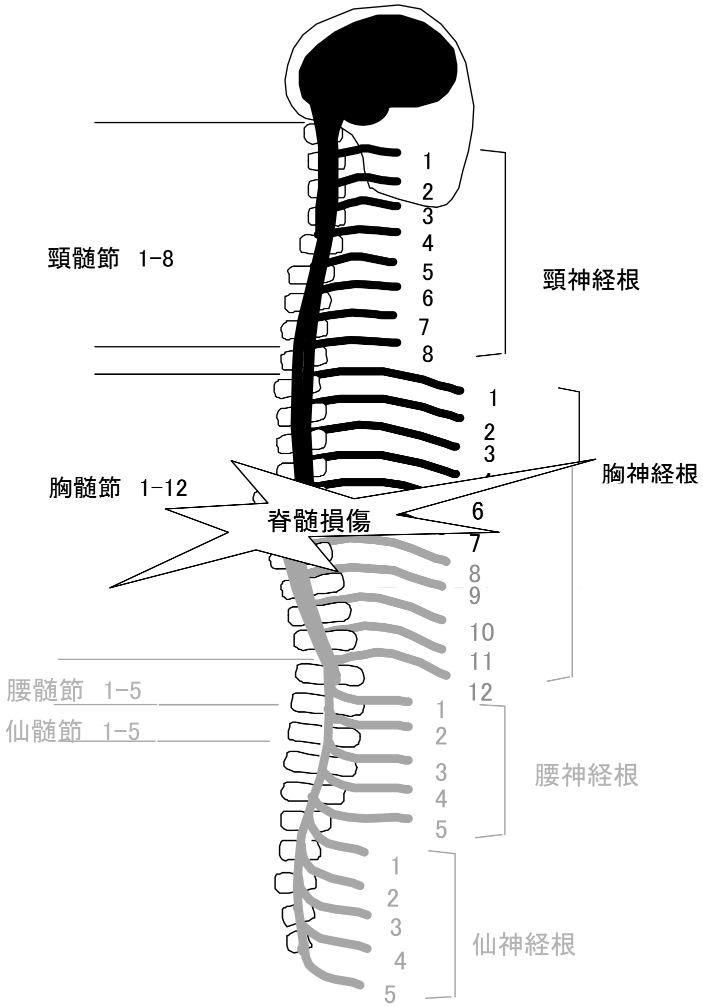
Wearable but the design is hard

Application of this type of robot
may be conductive to disuse syndrome

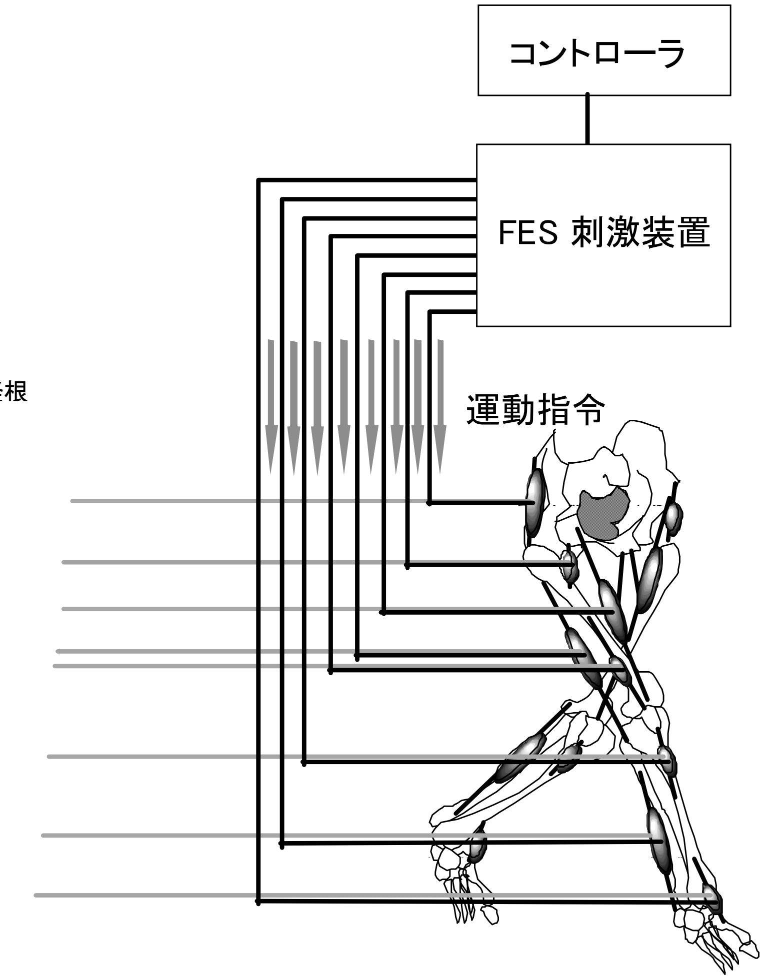


Lower-extremity exoskeleton.
(Gabriel Ollinger, w. Honda Res. Inst.)

With treadmill

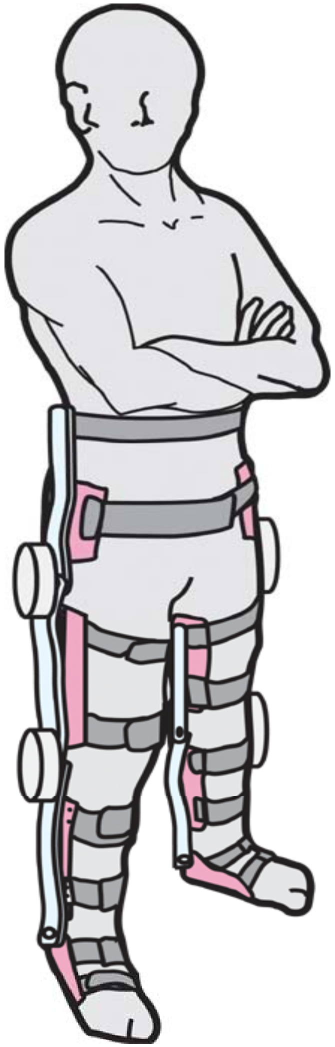

頸髄節 1-8
胸髄節 1-12
腰髄節 1-5
仙髄節 1-5
頸神経根
胸神経根
腰神経根
仙神経根
脊髄損傷

脊椎と中枢神経系


コントローラ
FES 刺激装置
運動指令

Further researches

- **Fitting to individuals**
- **Multiple usages in training and daily living**
- **Commercially distribution as active prosthetic leg**
- **Appeal for preventing disuse syndrome**
- **Marketing and feedback from the users**



Concluding remarks

- It is shown we can simulate human movements
- Robot technology is coming close to human movements
- We can apply robot technology to reconstruction of human functions, rehabilitation, and training

Finally

- Using system identification techniques, we can obtain a model which represent the subject. It is used for evaluating the designed device to the subject.

- We can evaluate virtually a design using model-based method before making it actually.

- New assistive devices can be tested by using model-based method without taking risks.
- Quantitative evaluations are possible for conventional devices.
- Optimization on assistive devices can be conducted.
- Most of the results can be applied to humanoid robots.