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認知ロボティクス
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Motion Development as direct CPG adjustment by touching

接触教示に基づくCPGのパラメータ調整によるヒューマノイドロボットの運動生成

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Abstract
Central Pattern Generators (CPGs) are a powerful bio-inspired method to generate motions. Usually the numerous parameters of the CPGs are set by learning algorithms like genetic algorithms or policy gradient. This gives the user little control over the resultant motions, which might look awkward. We propose a methodology to set the CPG parameters by user interaction, in detail by touch interaction. We describe the elements of the developed system and verify its feasibility by the realization from scratch of a crawling motion.

概要
CPGによってロボットの運動を生成する場合，CPGのパラメータ調整の困難さが問題となる．通常，パラメータ調整は遺伝的アルゴリズムや方策勾配法などを用いて行われるが，望みの動作を実現するための評価関数の決定は困難である．一方，ユーザが手動でパラメータ調節を行う場合，パラメータ空間が大きく，パラメータ間の関係も複雑であることから直感的に調節することができない．そこで本研究では，ユーザが全身触覚センサを持つロボットを直接触ることでCPGのパラメータを調節し，目的の動作を生成する手法を提案する．

Concept

- **CPGs have numerous parameters to be set**

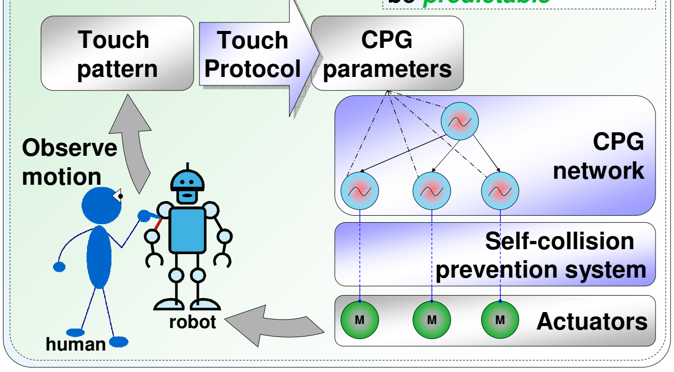
•Manually set the parameters
•Pros:
o Human can provide a good evaluation of the motion
o Control on the resultant motion
•Cons:
× Unintuitive (difficult to predict the effect of parameter changes)
× Time consuming

•Set the parameters by search algorithms
•Pros:
o no user effort, parameters automatically detected
•Cons:
× difficult to formalize good evaluation function
× Little control on the resultant motion (often awkward)

•Use *touch* to set the CPG parameters:
- Intuitive
- Complete control over the resultant motion

Fundamental elements:
- •Touch protocol
- •CPG Network
- •Self collision prevention system

•Touch protocol needs to be intuitive
•Effect of the CPG parameters changes to resultant motion must be *predictable*

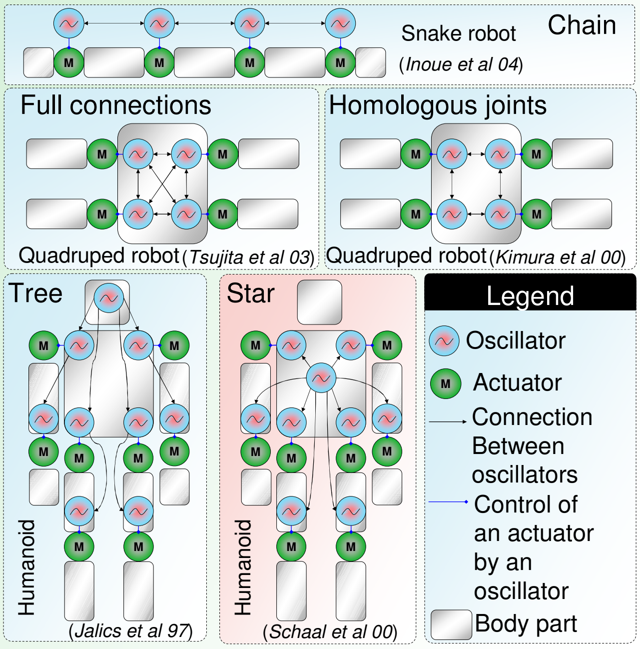


Related works

Human intuition often employed for motion development
(*Breazeal 04*), (*Ikeura et al 90*), …

Several Oscillators available:
- •Sinusoidal (*Morimoto et al. 06*)
- •Hopf/adaptive frequency Hopf(*Righetti et al. 06*)
- •Rayleigh (*De Pina Filho et al. 05*)
- •Van der Pol (*Veskos et al. 05*)
- •FitzHugh-Nagumo (*Collins et al 94*)
- •Hopfield (*Mathayomchan et al 02*)
- •Matsuoka (*Inada et al 03, Inoue et al 04*)
- • …

Five network structures usually employed in literature



We chose the Hopf oscillator and the star topology for their *generality* and *predictability*

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Oscillator Model

$z_j \in \mathbb{C}$ state variable

$\gamma \in \mathbb{R}$ recovery speed after perturbation

$F_j \in \mathbb{C}$ external perturbation signal (from reference oscillator)

$$\dot{z}_j = \gamma\,(\mu_j - |z_j|)^2 z_j + i\omega_j z_j + F_j(t)$$

$\mu_j \in \mathbb{R}$ oscillation amplitude parameter

$$\omega_j = p_j \omega_0$$

$\omega_0 \in \mathbb{R}$ reference oscillator frequency parameter

$p_j \in \mathbb{N}$ frequency parameter

$z_{j0} \in \mathbb{C}$ state variable of the reference oscillator

$m_j \in \mathbb{C}$ signal sent to the actuator

real part

$$m_j = \Re\{z_j\} + o_j \qquad F_j(t) = w e^{i\phi_j} z_0^{p_j}$$

$o_j \in \mathbb{R}$ oscillation center (offset) parameter

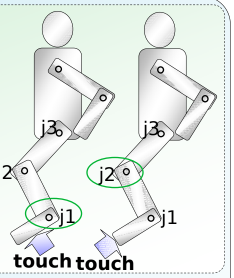
$w \in \mathbb{C}$ coupling coefficient between the oscillators

$\phi_j \in \mathbb{R}$ phase parameter

Touch protocol

Determination of the oscillator whose parameters should be modified:

- Most distal joint that generates a movement in the direction normal to the sensor surface



Determination of the parameter change

- Time reference: oscillator phase
- τ_s pushing time
- $\rho_{j_s} = \langle n_s, d_{j_s} \rangle$ dot product between
  - n_s normal to the pressed sensor surface
  - d_{j_s} derivative of the position of the center of sensor s when selected joint j_s is rotated
- Constants $\Theta_O = \pi$, $\Theta_A = \frac{1}{6}\pi$, $\Theta_P = \frac{2}{3}\pi$
  $\Delta_o = \Delta_A = \frac{1}{12}\pi$, $\Delta_{\omega_0} = 1$

Offset
Very long push
$\tau_s > \Theta_O$
↓
$o_{j_s} \mathrel{+}= sgn(\rho_{j_s})\Delta_o$

Amplitude
medium push
$\Theta_A < \tau_s \leq \Theta_O$
↓
$\mu_{j_s} \mathrel{+}= sgn(m_{j_s}\rho_{j_s})\Delta_A$

Phase
single tap
$\tau_s \leq \Theta_A$
&
No push for Θ_P
↓
$\phi_{j_s} \mathrel{-}= \angle(m_{j_s} z_{j_s})$

Frequency
double tap
short-short = increase frequency
short-long=decrease frequency
$\tau_s \leq \Theta_A$
& second push before Θ_P
$\tau_{s2} \leq \Theta_A$ ↓ $p_{j_s}{+}{+}$
$T_{s2} > \Theta_A$ ↓ $p_{j_s}{-}{-}$

Special case: touch robot body=change ω_0
$\tau_{s2} \leq \Theta_A$ ↓ $\omega_0 \mathrel{+}= \Delta_{\omega_0}$
$T_{s2} > \Theta_A$ ↓ $\omega_0 \mathrel{-}= \Delta_{\omega_0}$

Self collision prevention system

Some CPG parameter settings cause self collisions

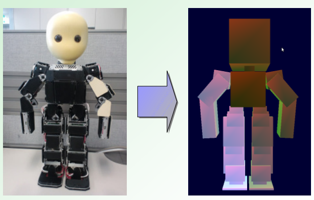
↓

Real hardware can be damaged, online fast prevention of self collisions required

guarantee to detect collision postures ⇔ No need to detect collision-free postures with high precision

Avoid useless computation:
- ***direct mapped cache of postures*** (useful for periodic motions):
  - address is an hash of the angles, discretized by 1˚
  - content = collision yes/no
- list of parts that cannot collide
- list of parts moved when a single joint is rotated

Simplified model: links modeled as parallelepipeds

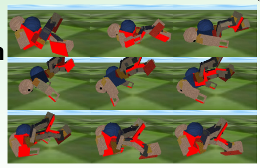


Experiment

Realization of crawling, sidestepping, walking
employing a simulator, touch=clicks on the link surfaces

motion	Development Time (min)	Offset changes	Amplitude changes	Frequency changes	Phase changes
crawling	56	22	57	2	39
sidestep	29	56	31	4	18
walking	34	132	60	15	28

Comparison: optimization of the parameters by **Genetic Algorithm**
(population size 20, 60 generations, real value encoding, roulette wheel selection, mutation probability 1)
- Task achieved but motion looks awkward
- Larger ranges for the pitch and roll



Future works

- Distinguish between user touches and floor contact
- Introduction of feedback to entrain to the environment
- Implementation on the real hardware

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