Design and Optimization of Human Motion and Motion Aid Increasing Quality of Life

QOL向上のための運動と補助器の最適化設計

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Background

- Mechanical engineering, Robotics, Mechatronics, ...
  - Production of useful tools
  - New technologies
    - Mechanism, Sensor, Actuator, Electrical device, etc.
  - Focus
    - Machine creation that works on behalf of the human

- Research field derived from Mechanical engineering
  - Human centric design, Human machine coexistence
  - Machine/Technology creation that increases QOL
  - Delight design or Amenity design
Purpose of this project

- Development of technologies for increasing human Quality of Life
  1. Human motion analysis and optimization based on body dynamics
  2. Design of assistive aids for human life/motion
     - Active/Passive mechanism
     - Self-ownership of the mechanism
  3. Amenity space design for comfortable life

Collaboration

MIT : Prof. Asada
Tokyo TECH : Prof. Okada

- Research interests
  - Human machine coexistence
  - Human motion analysis and design (kinematics/dynamics)
Research sources (Prof. Okada, Tokyo TECH)

1. Human assistive device
   - Passive walking aid for our daily life
     - Challenge
       - Appropriate assistive force
       - Realization by a nonlinear spring (design of nonlinear spring)

Research sources (Prof. Okada, Tokyo TECH)

- Assistive force
  - Motion capture and inverse dynamics
    - Energy accumulation

- Nonlinear spring
  - Two characteristics
  - Grooved cam

Energy release
Energy accumulation
Spring

5th order polynomial

F [N]

ϕ [rad]

-0.2
0.4
0.6

-30
-20
-10
0
10
20
30

-30
-20
-10
0
10
20
30

Research sources (Prof. Okada, Tokyo TECH)

2. Human motion analysis and motion instruction using enhanced motion

- Target: Chest compression
  - First aid cardiac compressions
  - Enhanced motion
    - He generates 480N (about 70% of his body weight)
    - It requires larger force than it looks
    - It is difficult to see only from a demonstration

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Research sources (Prof. Okada, Tokyo TECH)

- Human dynamics
  \[ M(\theta)\ddot{\theta} + C(\theta, \dot{\theta}) + K(\theta) = \tau \]
- Motion modeling
  - Autonomous controlled system
   \[ \tau = h(\theta) \]
  - The controller is decomposed into ‘reference generator’ and ‘feedback gain’
   \[ \theta^{ref} = -\left( \frac{\partial h(\theta)}{\partial \theta} \right)^{\#} h(\theta) + \theta \]

Enhanced motion = Pseudo-reference
Research sources (Prof. Okada, Tokyo TECH)

- Enhanced motion for chest compression

![Diagram of enhanced motion for chest compression]

- Application to sports instruction

Research sources for collaboration

- Robust motion optimization
  - robot control
  - human motion design
  
point of view
Research sources for collaboration

- **Accuracy of robot control**
  - Iterative assessment → average and variance
  - Sensitivity analysis (analytical)

\[
\dot{x} = f(x) + g(x)u
\]
\[
x(t_e) = \int_0^{t_e} f(x)dt + \int_0^{t_e} g(x(\tau))u(\tau - t)d\tau
\]
\[
\frac{\partial x(t_e)}{\partial \ell} = \ldots
\]

Dynamics sensitivity
Low sensitivity is required

- **Human skilled motion**
  - Ex.: Free-throw in basketball
    - High shoot average even though the existence of the perturbation
      → **Low sensitivity**

- **Purpose**
  - Sensitivity analysis (dynamic/kinematic)
  - Optimization of the throwing motion
    (low sensitivity motion)
**Research sources for collaboration**

- Dynamic sensitivity analysis of throwing motion
- Problem formulation

\[ \Delta \theta_0, \Delta \dot{\theta}_r \]

Sensitivity analysis \( \Delta \theta_0 \rightarrow \Delta x_r \)

The lower sensitivity has the higher accuracy

**Research sources for collaboration**

- Calculation results

\[ \Delta x_r \rightarrow \Delta x_s \]

Comparative release point

\[ 36.1 \rightarrow 139.2 \]

Minimum sensitivity

**Accuracy of landing point**

- Histogram of landing point

\[
\begin{align*}
\frac{36.1}{139.2} &= 0.259 \\
\sqrt{\frac{0.030}{0.474}} &= 0.252
\end{align*}
\]
Collaborative research

Towards human motion
- Free-throw in basketball
- Motion optimization with small sensitivity

Challenge
- **Whole body motion**: redundancy
  - *Synergy*-based motion analysis
  - *Sensitivity*-based optimization

To other dynamic motions
- Gymnastics, Football, Daily life, etc.

Assistive tool design

Collaborative research

Application to robotics
- Bipedal robot
  - Controller stabilizes the robot
  - Reference is designed based on the robot dynamics
  - So many sensor information

**Dynamics sensitivity analysis**
- Reference $\rightarrow$ motion perturbation *Robust trajectory design*
- Sensor noise $\rightarrow$ motion perturbation *Robust sensing*
  - Which sensor data is useful or important?