Real-Time Motion Generation for Humanoid Robot

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Outline

• Motivation

• State of the Art

• Our Scheme

• Simulations and Experiments
Motivation

Fig. 1 Gaze at the moving target.

Fig. 2 Gaze at each other.

Fig. 3 Moving something.

Fig. 4 Dual-arms corporately complete a task.
Motivation

• Motivation of Neck-Eyes Motion

  – In daily life, neck-eyes express rich information about a person’s activity, and thus play an important role in daily life.

  – Neck-eyes make the robot to appear very vivid.

  – Neck-eyes are the base of attention.
Motivation

• Motivation of dual-arms motion generation
  – The two arms are more like human body, which are easy to transfer the motion to the remote robot in teleoperation [1].
  – Two arms are more flexible and stiff [2]. Many daily work need two arms to corporately complete. For instance, moving heaving box, peg-in-hole task, screw assembly where one arm controls the Nut and the other the bolt.
  – Two arms are more natural and can be used to understand human’s motion (body languages).

Motivation

Humanoid robots are expected to mimic human behaviors, act and manipulate objects in ways similar to humans [3].

Therefore, real-time motion generation of neck-eyes and dual-arms play an important role in Humanoid Robot.

State of the Art

- Ref. [4] provides a neck and eyes coordination

- Shortages:
  - Only works in virtual environment

State of the Art

- Ref. [5] provides a neck–eyes coordination model

- Shortages:
  - Just gave the *approximate* solution, but did not give out the analytical solution;

Fig. 6 Approximate neck-eye coordination model [5].

State of the Art

• Analytical solution [6]

• Shortages:
  -- Just works in some special arms;
  -- Most for the non-redundant arm[1].

Fig. 7 Robot presented in [6].

State of the Art

- Pseudoinverse-based method[7]

- Shortages:
  - Need to compute matrix inverse, which are time consuming for real-time systems.
  - Cannot solve the inequality problems.

Fig. 8 Mobile robot presented in [7].

State of the Art

- Optimization methods (recent trend) [8,9].

Advantages:
- Need not to compute matrix inverse;
- Can consider the inequality problems;
- Easy to consider human-like constraints;
- ...


Ref. [10] points out that the QP-based optimization schemes can be used to dual-arms situation.

Our Scheme

- Propose an online motion generation scheme which considers head-eyes and arms motion for a humanoid robot.

Fig. 9 Frame assignments for Nadine robot.
Our Scheme

Fig. 10 System Architecture
Our Scheme

• What is new? (contributions)
  – The proposed scheme not only considers the dual-arm motion generation, but also considers the head-eyes motion.
  – It is a general optimization scheme of dual-arm redundancy resolution, which can consider different optimization index according to different goals.
  – Explicit analytic solution to the neck-eyes motion (which can get exact solution).
  – Propose a vision-based evaluation method. The quality of the robot movements is assessed through comparisons with human movements.
Our Scheme

• What are the challenges?

  -- Redundancy resolution problem;

  -- Consider both the head-eyes and the dual-arms;

  -- Human-like behaviors;

  -- Real-time computing.
Kinematic model

- Head-eyes motion generation

Fig. 11 The key points when the neck and the eyes turns up and down.

Fig. 12 The angles of pitch of the neck and eyes when $T_z > T_{N_U\text{limit}Z}$. 
Kinematic model

- Head-eyes motion generation

**Fig. 13** The angles of pitch of the neck when $\theta_{\text{NUD}} = \theta_{\text{NUlim}}$.

**Fig. 14** The turning angle of the neck when $\theta_{\text{NUD}} = \theta_{\text{NDlim}}$. 
Kinematic model

- Head-eyes motion generation

Fig. 15 The angles of pitch of the neck and eyes when $T_z < T_{N\text{U}limitZ}$.

Fig. 16 The key angles when the neck and eyes turns left and right.
Our Scheme

- The kinematic control process

Fig. 17 The kinematic control process.
Our Scheme

\[
\begin{align*}
\text{minimize} & \quad \dot{\vartheta}^T M \dot{\vartheta} / 2 + b^T \vartheta \\
\text{subject to} & \quad j(\vartheta) \dot{\vartheta} = \ddot{\Upsilon} + k(\vartheta - f(\vartheta)), \\
\zeta_{\text{new}}^-(t) & \leq \dot{\vartheta} \leq \zeta_{\text{new}}^+(t).
\end{align*}
\]

\[
\begin{align*}
\zeta_{\text{new}_i}(t) & = \max\{\dot{\vartheta}_i^-, \nu(\vartheta_{\text{new}_i}(t) - \vartheta_i)\} \\
\zeta_{\text{new}_i}^+(t) & = \min\{\dot{\vartheta}_i^+, \nu(\vartheta_{\text{new}_i}(t) - \vartheta_i)\}
\end{align*}
\]

\[
\dot{\vartheta}_{\text{new}}^\pm(t) = \vartheta^\pm + \frac{\vartheta_{\text{diff}}^\pm}{1 + e^{-(t - T_{\text{SP}})/c_{\text{tuning}}}},
\]
Our Scheme

- Linear variation inequality based primal dual neural network (LVI-PDNN)

\[
\begin{bmatrix}
\dot{\Theta} \\
\dot{y}
\end{bmatrix} = \gamma \left\{ P_{\Omega} \left( \begin{bmatrix}
\dot{\Theta} \\
y
\end{bmatrix} - \left( \begin{bmatrix}
I & -J^T \\
J & 0
\end{bmatrix} \cdot \begin{bmatrix}
\dot{\Theta} \\
y
\end{bmatrix}
\right)
+ \begin{bmatrix}
0 \\
-\dot{\gamma}
\end{bmatrix} \right) \right\}
\]
Simulations and Experiments

Fig. 18 Robot motion trajectories when tracking a flying ball along a circle path.
Simulations and Experiments

Fig. 19 Angle of pitch of neck

Fig. 20 Angle of rotation of neck
Simulations and Experiments

Fig. 21 Angles of pitch of eyes

Fig. 22 Angles of rotation of eyes
Simulations and Experiments

Fig. 23 Close shot of gaze.

Fig. 24 Interaction between a human and a robot with the gaze.
Simulations and Experiments

• Play ball game by using dual-arms

Fig. 25 Nadine plays ball task.
Simulations and Experiments

- Applied to pointing towards sound source

Fig. 26 Pointing towards sound source.
Simulations and Experiments

Table 1 Average Computing Time Within Each Sampling Interval and Total Computing Time When the Robot Points toward Sound

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<thead>
<tr>
<th>#</th>
<th>$\tau_{\text{Ave}}$ (s)</th>
<th>$\tau_{\text{Sum}}$ (s)</th>
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Simulations and Experiments

Table 2 Positioning-errors of end-effectors when pointing towards different position.

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<th>Average errors</th>
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</table>
Simulations and Experiments

Fig. 27 Dual-arms’ joints by using the proposed scheme.

Fig. 28 Dual-arms’ joints by using pseudoinverse-based scheme.

Comparison shows that the proposed scheme is more effective and applicable.
Simulations and Experiments

- Human-like evaluation: Pearson product-moment correlation

Fig. 29 Skeletons of humans and robot.

The computed results show that all the values are significant ($p < 0.01$ in most cases), and most of the values are very high (more than 90%).
Publications

• [1] Zhijun Zhang, Aryel Beck and Nadia Magnenat-Thalmann, “Human-Like Behavior Generation Based on Head-Arms Model for Tracking External Targets and Body Parts,” IEEE Transactions on Cybernetics (Accepted, Q1)


Any questions?