A Biped Robot that Keeps Steps in Time with Musical Beats while Listening to Music with Its Own Ears

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Music-synchronized ASIMO

- Autonomously keep steps in time with musical beats

Backgrounds

- Entertainment music robots
  - Reaction to music (sounds)
    - Moving/Rolling
    - Lighting

MIURO

Rolly

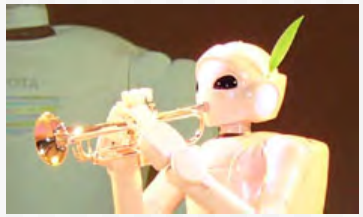
- Humanoid robots
  - Conventional research directions
    - Walking/Running
    - Manipulation

- Human-robot interaction through music
  - Application for entertainment use
    - Importance of music appreciation
    - Hand-clapping/Foot-tapping

HRP-2

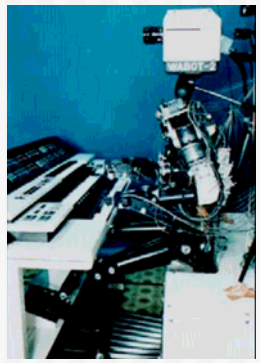
State-of-the-art music robots

- Physical functions
  - Trumpet player
  - Robot dancer



Programmed in advance

- Physical and Intelligent functions
  - Organ player
    - Read musical scores
  - Dance partner
    - Predict human's movements

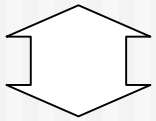


No music-listening function

Music robots should listen to music by using their own ears

Our approach

- Development of an intelligent robot dancer with a music-listening function
  - Intelligent function
    - Understand musical audio signals
      - Detect/predict musical beats
      - Use robot's own ears (microphones)



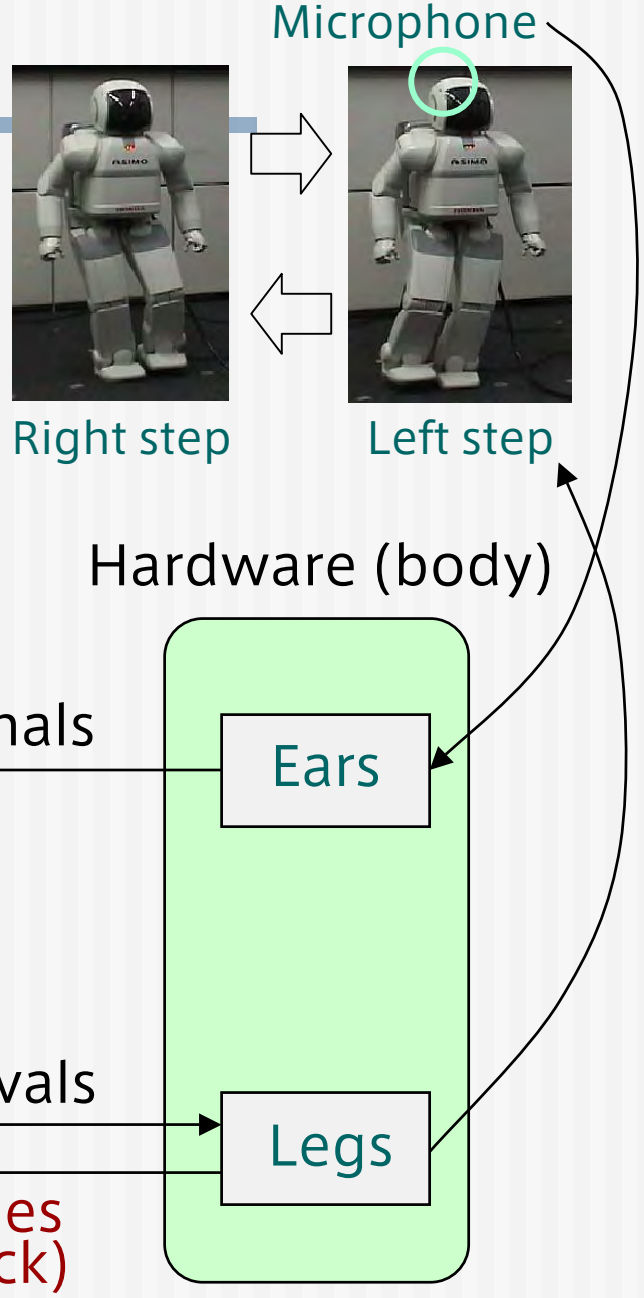
Integration

  - Physical function
    - Control dancing movements
      - Synchronize robot's steps with musical beats

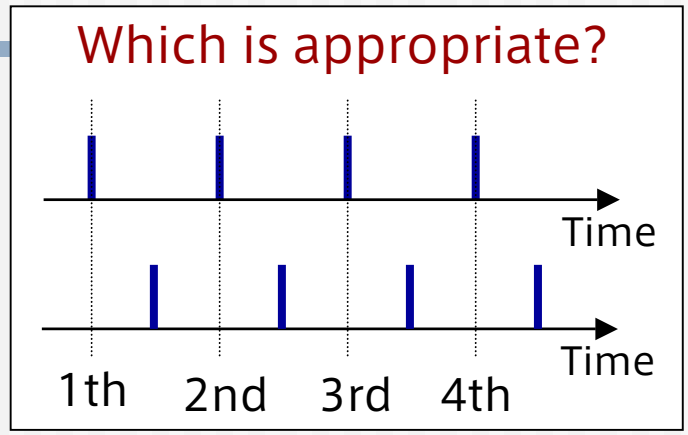
Real-time integration of asynchronous functions

Architecture

1. Record audio signals
2. Detect beat times
3. Synchronize step times



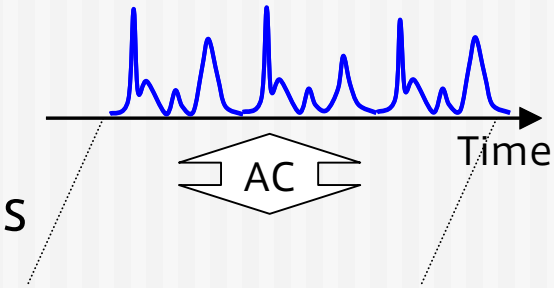
Real-time beat tracking

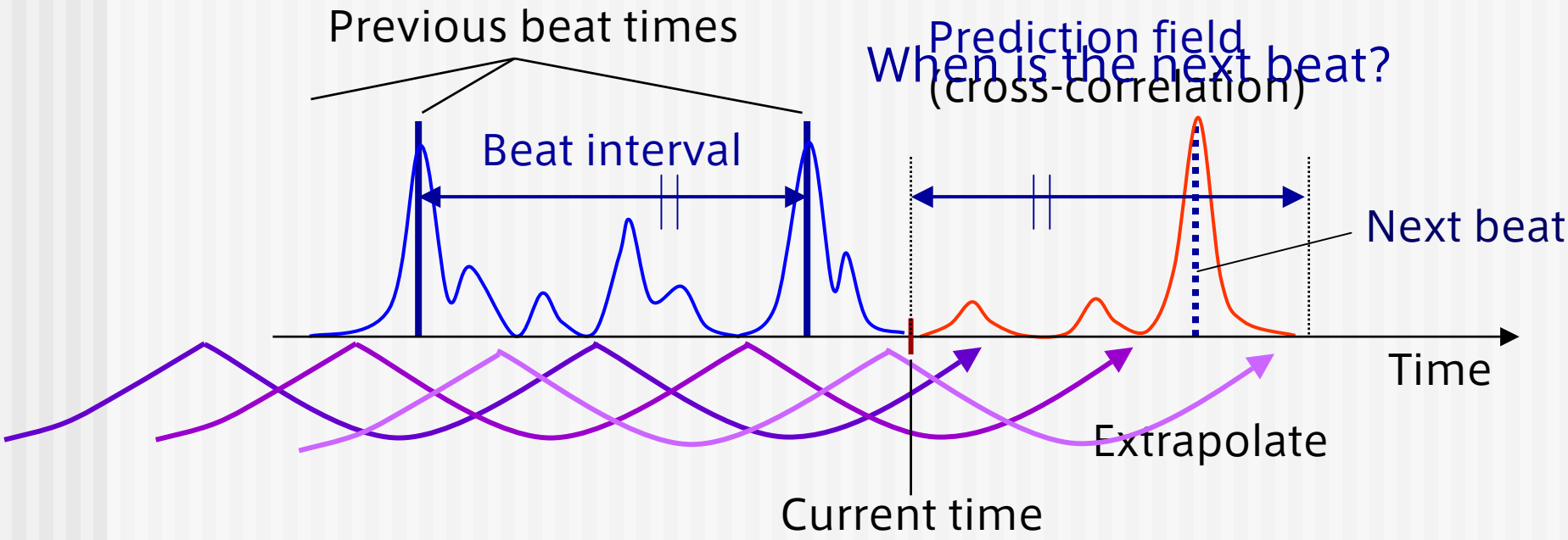


- Goal
  - Predict next beat time
    - Detect previous beat times
- Issues
  - Ambiguity of beat-time interpretations
    - Selection of musically-appropriate interpretation
  - Noisy environments
    - Recovery from inappropriate interpretation
- Approach [Goto2001]
  - Multi-agent architecture
    - Twelve agents with different interpretations
    - Evaluation of interpretation reliability
      - Focus on chord changes and drum-sound onsets

Beat prediction by each agent

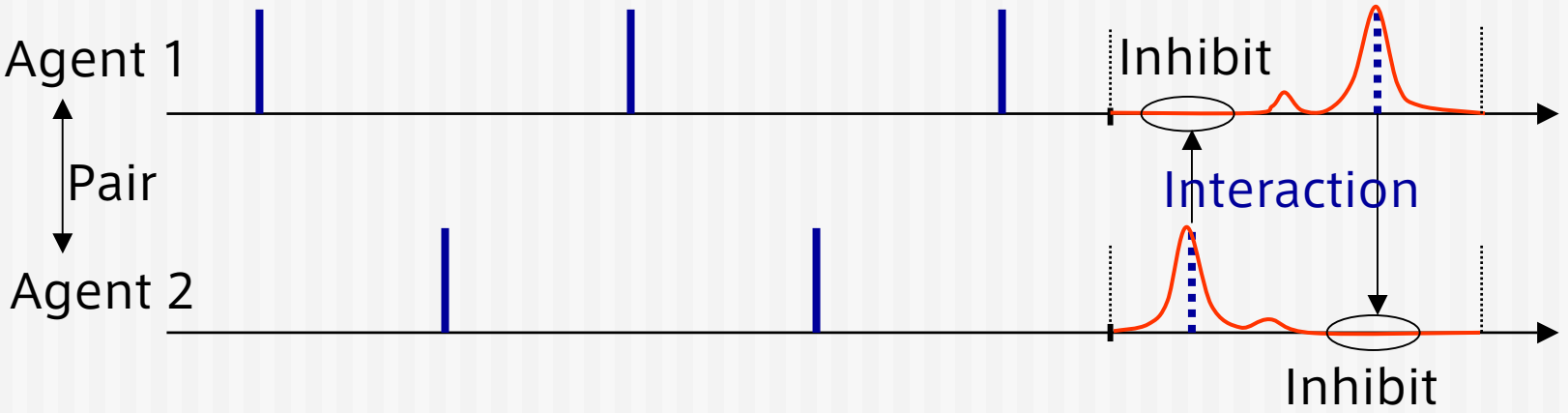
1. Calculate onset reliability at each time
   - Onset reliability ∝ Power increase
2. Estimate beat interval
   - Auto-correlation of onset reliabilities
3. Predict next beat time
   - Cross-correlation of onset reliabilities





Integration of multiple agents

- Interaction of paired agents
  - Half-beat-gaped beat-time interpretations



- Selection of most reliable interpretation
  - Musical-knowledge-based reliability evaluation
    - Coincidence of beat times with musical cues that are likely to occur at beat times
      - Chord changes
      - Drum-sound onsets

Feedback control

- Adjustment of intervals and timing
  - Error reduction

Step interval $I(n+1)$
(Command)

Step time $T_{step}(n)$
(Feedback)

Next beat time
$T_{beat}(n+1)$

Speaker

Music CD

Timing: $T_{step}(n+1) \rightarrow T_{beat}(n+1)$

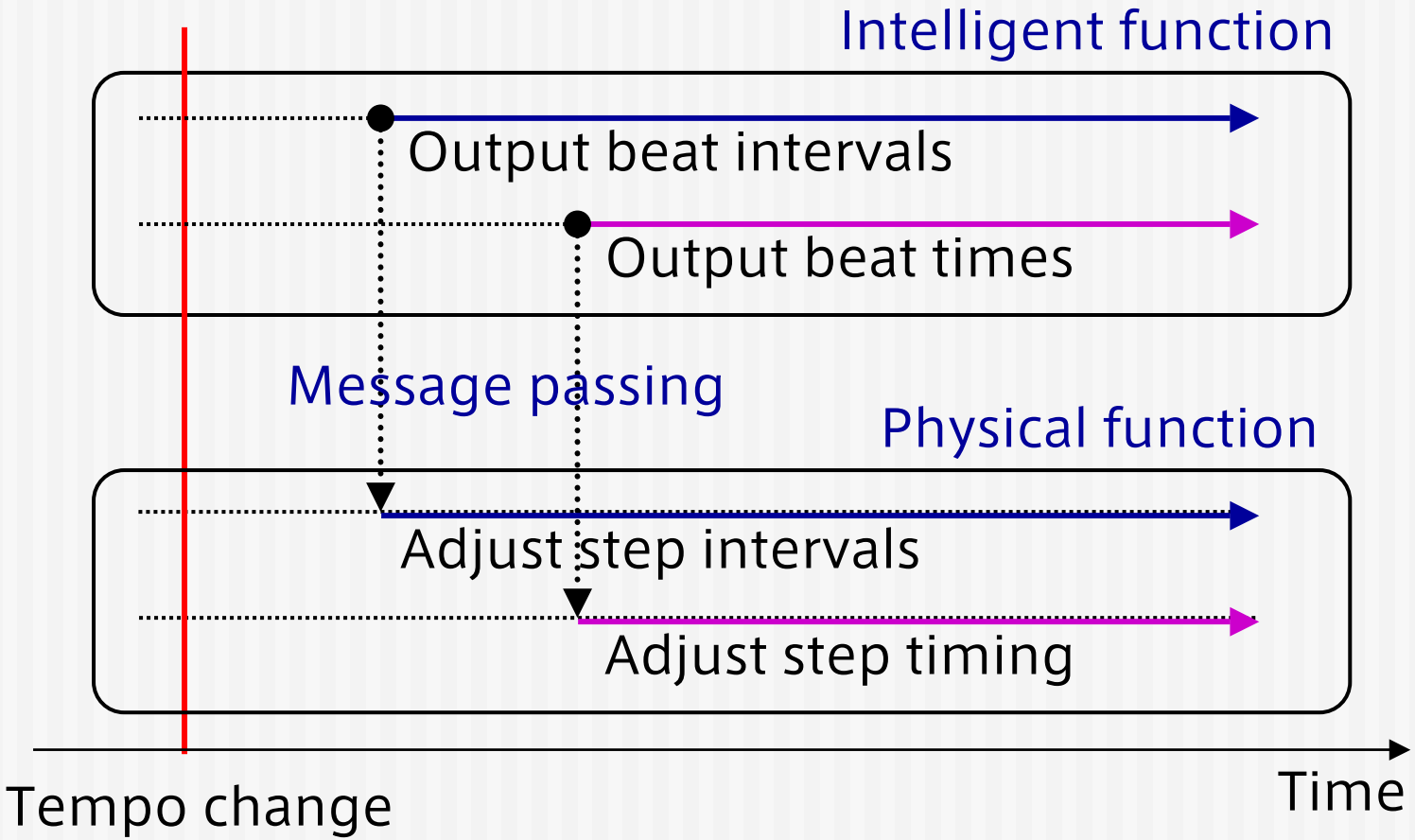
Interval: $T_{step}(n+1)-T_{step}(n) \rightarrow T_{beat}(n+1)-T_{beat}(n)$

$$I(t+1) = I(t) + \beta_I(\text{IntervalError}) + \beta_T(\text{TimingError})$$

0.30 0.02

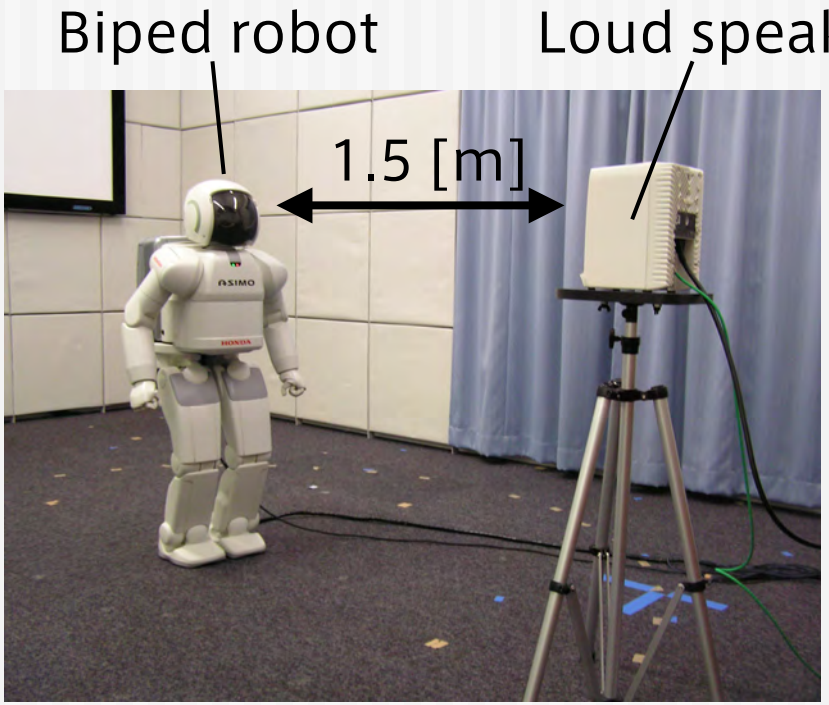
Pipeline-processing-like integration

- Prompt response to tempo changes
  1. Interval adjustment
  2. Timing adjustment



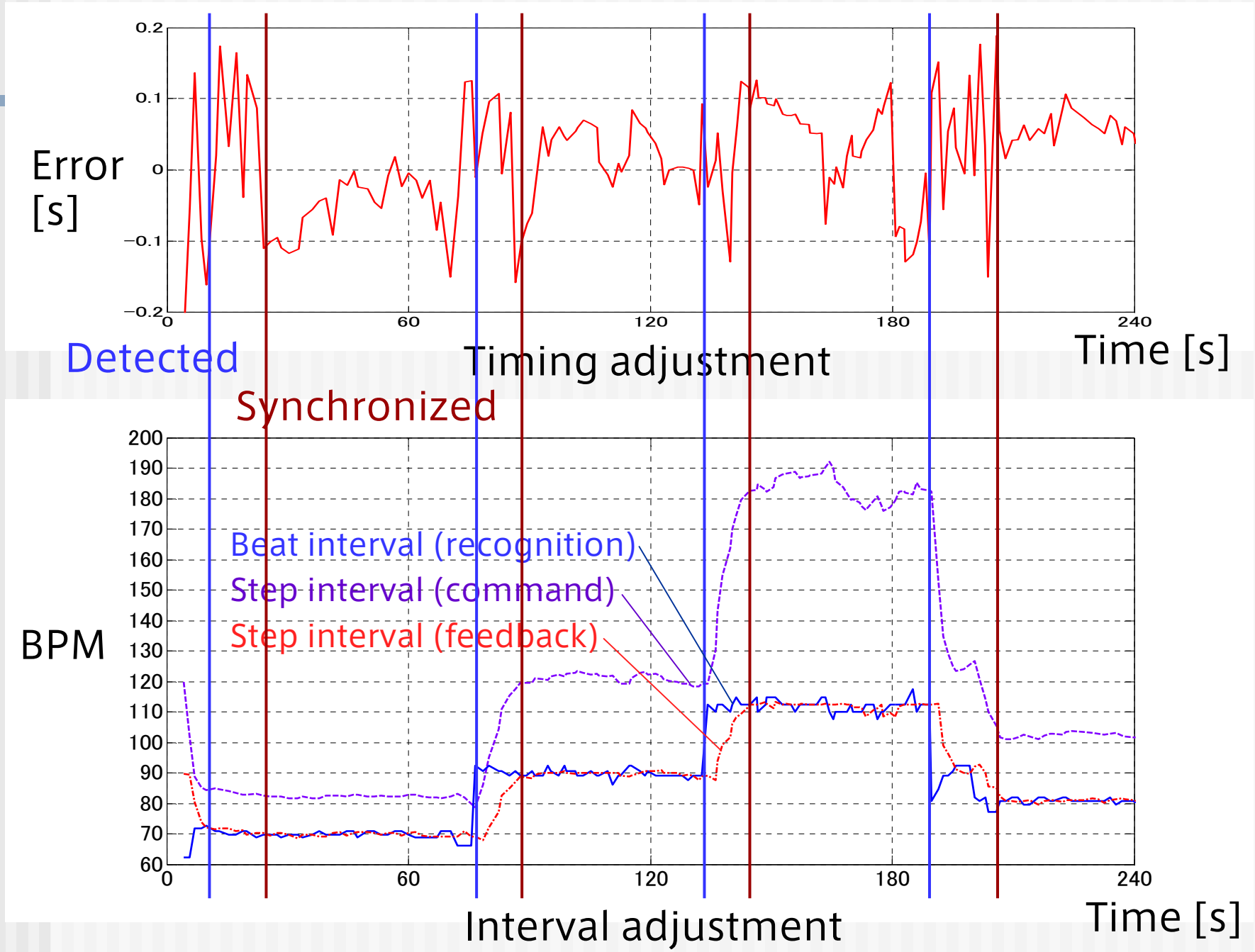
Experiment

- Used data
  - Excerpts of popular songs from RWC-MDB-P-2001
    - Concatenated excerpts: 60 [s] x 4 [excerpts]
    - Tempo changes (bpm: beats per minute)
      - 70 → 90 → 112 → 81 [bpm]



- Standard room
- Standard loud speaker
- Honda ASIMO

- Single microphone
  - Embedded in head
- Machine: Core2 2GHz


Error [s]
0.2
0.1
0
−0.1
−0.2
0
60
120
180
240
Time [s]
Detected
Timing adjustment
Synchronized
BPM
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
Beat interval (recognition)
Step interval (command)
Step interval (feedback)
Interval adjustment
Time [s]

Conclusion

- Goal
  - Development of an intelligent robot dancer
- Approach
  - Integration of intelligent and physical functions
    - Real-time beat tracking
    - Feedback step control
- Results
  - Achieved autonomous synchronization of robot's steps with predicted musical beats
- Future work
  - Introduce complex dancing movements
  - Take into account musical moods
  - Enhance human-robot interaction