Architecture of a Cyberphysical Avatar

UTCS Real-time System Group
UT Human Centered Robotics Laboratory
UTCS Neural Networks Research Group
Outline

• Introduction
• Cyberphysical Avatar Research Issues
  – Mechatronics and Control of Humanoid Robots
  – Skill Acquisition by Machine Learning
  – Reliable and Real-time Avatar-Human Communication
• System Integration
• Ongoing and Future Work
Cyberphysical Avatar

A SEMI-AUTONOMOUS ROBOTIC SYSTEM:
- PERFORMS PHYSICAL TASKS SUBJECT TO TIMING CONSTRAINTS
- ADJUSTS TO UNSTRUCTURED ENVIRONMENTS
- UNDER HUMAN SUPERVISION

Enormous Economic and Social Impact (robot-assisted eldercare, disaster rescue ... )
Challenges

• Dynamics and Control of Humanoid Avatars
  – Modeling the dynamic behavior of physical avatars interacting with humans in unstructured environments
  – Body-compliant control for safety-critical cooperative tasks
Challenges

• **Skill Acquisition by Machine Learning**
  – The conversion of human operator commands to avatar behaviors
  – The optimization of robot behaviors in response to the environment
Challenges

• Reliable and Real-time Avatar-Human Communication
  – QoS-guaranteed remote avatar-human communication
  – Real-time and reliable wireless communication for local control
MECHATRONICS AND CONTROL OF HUMANOID AVATAR
Mechatronics Design of Dreamer Robot (Professor Luis Sentis)

- Robotic system (91 kg, 1.65m) 31 DOF with compliant control

- Humanoid upper body (28 DOF)
  - 2-DOF torso, 12-DOF arm, 14-DOF head

- Educational Holonomic Mobile Base (3 DOF)
  - 3 Omnidirectional Wheels
Embedded System Communication Architecture for Dreamer

- Smaller boards in both base and upper body
  - Powers motor controllers
  - Integrates sensor signals
  - Handle EtherCAT communication

- Real-time PC (Ubuntu + RTAI)
  - Meka M3 control software
  - Whole-body control software

- Modules connected through an EtherCAT hub
Whole-body Compliant Control Framework

• Goal: enable humanoids to manipulate and maneuver in their environments through whole-body multicontact interactions.

• A skill is defined as a juxtaposition of multiple operational tasks to help translate between higher-level goals and the low-level tasks.

• In the control structure, low-level tasks are aggregated using a hierarchy. Lower-priority tasks operate in the null space of all higher priority tasks to ensure no interfere with higher levels tasks.
Whole-body Compliant Control Framework

The Dreamer robot crosses a terrain with a slope while responding to human interaction
Whole-body Compliant Control Framework

Task Specifications

**Task 1:** Maintaining coordinates of center of mass

**Task 2:** Compliant hand position enabling the robot to respond to compliant human interaction

**Task 3:** Stabilize self-motion and converge to a human-like posture

The Dreamer robot crosses a terrain with a slope while responding to human interaction
LEARNING HOW TO
GRASP
How to Perform Grasping of Objects?

• Limitations of existing approaches
  – Assume full knowledge of the 3D model of objects
  – Supervised learning approaches need carefully constructed examples to represent correct or optimal performance
  – Not tested through real-world experiments

• Question: How do we assist robots to learn tasks of grasping 3D objects with any shape?
Grasping Learning Using NEAT (Prof. Risto Miikkulainen)

- Neuroevolution of Augmenting Topologies (NEAT)
  - Based on exploration and reinforcement
  - Alters both the weighting parameters and structures of networks
  - Incrementally grows from minimal structure
  - Suitable for discovering sequential behaviors including robot navigation, arm control, and grasping
Learning in the GraspIt! Simulation Environment

- Improve the hand model of Meka robot and movement functionality in GraspIt!

- Simulate Kinect depth sensor data as input for the neural network

- Perform grasping task based on the output of the neural network

- Evaluate each grasp quality and Update the fitness function
The Proposed Learning Architecture

Grasplt! Simulation Environment

Input Layer

Kinect depth sensor data

Hidden Layer

Output Layer

Hand position (X, Y, Z)

Rotation Axis (x, y, z)

Angle of Rotation (r)

The coordinates of mouse click (a, b)
The Proposed Learning Architecture

Grasplt! Simulation Environment

Input Layer

Output Layer

Kinect depth sensor data

Hand position (X, Y, Z)

Angle of Rotation (r)

The coordinates of mouse click (a, b)

Item 1: distance between the output hand position ($P_i$) and a target object ($O_i$)

Item 2: quality ($Q$) of each grasp

Item 3: distance between the hand stop position ($S_i$) and the output position ($P_i$)

$$f(n) = \frac{\beta}{M+\alpha} + \gamma Q + \frac{\lambda}{N+\mu} \cdot \sum_{i=x,y,z} (P_i - O_i)^2 + \alpha \sum_{i=x,y,z} (S_i - P_i)^2 + \mu$$
The Flowchart of the Learning Experiments

**Training**
- Load a 3D world scene
- Capture depth array (20 X 20)
- Random select objects (x, y)
- Object Grasp Training
- Evaluation (Repeat 100 Generations)
- Build a Neural Network Model

**Testing**
- Get a 3D scene form Kinect
- Capture depth array (20 X 20)
- Select the desired object (x, y)
- Object Grasping Testing
- Meka hand grasps the desired object
REAL-TIME AVATAR-HUMAN COMMUNICATION
Reliable and Real-time Avatar-Human Communication Infrastructure
Reliable and Real-time Avatar-Human Communication Infrastructure
OpenFlow Network for QoS-Guaranteed Remote Communication

• Existing Internet architecture
  • Cannot provide deterministic QoS guarantee
  • Large jitters will severely degrade the control performance
  • Missing hard deadline of control messages may cause catastrophic damage

• OpenFlow
  • Makes deployed networks programmable
  • Controls how packets are forwarded
  • Implementable on COTS hardware
  • Makes networking innovation easier

Pronto 3295 OpenFlow Switch
OpenFlow Network for QoS-Guaranteed Remote Communication (Cont.)

### Flow Setup

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Testbed in UT ACES 5th Floor
OpenFlow Network for QoS-Guaranteed Remote Communication (Cont.)

Throughput without OpenFlow

Throughput with OpenFlow
WirelessHART: Real-time and Reliable Wireless Protocol for Local Control

**Low-power**
- 802.15.4-based low-power radio

**Real-time**
- TDMA and centralized management

**Reliable**
- Mesh networking
- Data link layer ACK and Channel hopping

**Secure**
- Data integrity on DLL
- Data confidentiality on network layer
End-to-end Inter-arrival Time Comparison between Wi-Fi and WirelessHART

- Configure device to transmit data every 20ms
- Dynamically enable WirelessHART channel blacklist if jammer is present

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**Without present of jammer**

**With present of jammer**
SYSTEM INTEGRATION
System Setup in UT Human Centered Robotics Lab

1. The Dreamer Robot
2. Robot Control PC
3. Kinect Laptop
4. Kinect Sensor
5. WirelessHART Receiver
6. IP Camera
7. WirelessHART Gateway
8. WirelessHART Access Point
Remote Control Application

1. Color image from Kinect sensor
2. Depth image from Kinect sensor
3. Image from IP camera
4. Image snapshot when user pressed the color image
Remote Control Application

“Touch” command to move the robot arm to the target location

“Incremental move” command to overcome the measurement error from Kinect sensor
ONGOING AND FUTURE WORK
Transitioning from Simulated to Physical Controller

- Implement the hand rotation skill in whole-body compliant control.
- Tune NEAT parameters and the fitness function.
- Train the neural network model using multiple objects with different shapes.
Higher Sampling Rate Required in Network-based Cyber-Physical Systems

• Challenges
  – Mechanic modules need high frequency and low jitter control
  – A platform for a wide range of wireless control applications: a good balance among sampling rate, energy consumption and real-time performance
High-speed Real-time Wireless Control

- Real-time Wi-Fi to support high speed control
  - Replacing 802.15.4 PHY with 802.11 PHY
  - Network-wide synchronization and power saving
Thanks and Questions?