Humanoid Robots

Sven Behnke

Computer Science Institute
Albert-Ludwigs-University of Freiburg
Outline

• Motivation
• Humanoid Projects
• RoboCup Humanoid League
• Team NimbRo
• Robots
  - Alpha
  - RoboSapien
  - Kondo
  - Toni
• Personal Robots
Need for Humanoid Robots

• Industrial robots not flexible enough for unmodified environments
• Separated from humans
• New applications: Service, household helper, entertainment, ...
• Interaction with people needed
• Human-like body helps when acting in environments designed for humans
• Intuitive multimodal communication
• Programming by demonstration, imitation learning
Artificial Intelligence Research

• Intelligence needs body (Embodiment) and interaction with environment (Situatedness)
• Since 1997 RoboCup competitions
• Soccer as new AI benchmark, successor of chess

<table>
<thead>
<tr>
<th></th>
<th>Chess</th>
<th>RoboCup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment</td>
<td>Static</td>
<td>Dynamic</td>
</tr>
<tr>
<td>State change</td>
<td>Turn taking</td>
<td>Real-time</td>
</tr>
<tr>
<td>Info. accessibility</td>
<td>Complete</td>
<td>Incomplete</td>
</tr>
<tr>
<td>Sensor readings</td>
<td>Symbolic</td>
<td>Signals</td>
</tr>
<tr>
<td>Control</td>
<td>Central</td>
<td>Distributed</td>
</tr>
</tbody>
</table>

• Humanoid robots as a tool to understand human
## Some Humanoid Robots

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Asimo</th>
<th>QRIO</th>
<th>H7</th>
<th>HRP-2P</th>
<th>Silf-H2</th>
<th>Johnnie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>130cm</td>
<td>58cm</td>
<td>147cm</td>
<td>154cm</td>
<td>25cm</td>
<td>180cm</td>
</tr>
<tr>
<td>Weight</td>
<td>54kg</td>
<td>7kg</td>
<td>58kg</td>
<td>58kg</td>
<td>730g</td>
<td>40kg</td>
</tr>
<tr>
<td>Speed</td>
<td>0.69/0.83m/s</td>
<td>0.33m/s</td>
<td>0.5m/s</td>
<td>0.55m/s</td>
<td>0.1m/s</td>
<td>0.61m/s</td>
</tr>
<tr>
<td>DOF</td>
<td>34</td>
<td>28</td>
<td>30</td>
<td>30</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>Leg</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Arm</td>
<td>7+2</td>
<td>5+Fingers</td>
<td>7</td>
<td>7</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Trunk</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Head</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Communication Robots

WE-4  Saya in front of rubber skin  K-bot  Kismet  Mexi

Manipulation Robots

Wendy  Cog  ARMAR  DLR Hand II  FZK-Hand
Humanoid Robot Projects

- Waseda Univ.: Wabot-1 (1973), WE-4, Wendy
- Honda: Asimo, since 1986, > $100M
- Sony: QRIO (near production, entertainment)
- Toyota: Trumpet player announced for Expo 2005
- Japan: Atom-Project, Time: 30 years
- USA: Cog, Kismet, Leo, Nursebot
- Germany:
  - Johnnie (TU München)
  - ARMAR (SFB 588 Karlsruhe)
  - Mexi (C-Lab Paderborn)
  - DLR hand, lightweight arm
  - BW Univ. München Hermes
Soccer Leagues

Simulation

RoboCup actually is about playing soccer!

SmallSize

Sony Aibo

MidSize

Humanoid
RoboCup Humanoid League

• Since 2002

• Step towards long-term goal: “By the year 2050, develop a team of fully autonomous humanoid robots that can win against the human world soccer champion team.”

• So far, preliminary competitions:
  - Walking
  - Penalty kicks
  - Free performance
  - Technical challenges
2002 Fukuoka

10 teams

Footprints  Robo Erectus  Hoap-1  Nagara  Priscilla
2003 Padova

- 7 teams
- Honda Asimo prototype participated as HITS Firstep and won

HITS Firstep  Senchans  Robo Erectus  Foot-Prints  Isaac  Tao-Pie-Pie
2004 Lisbon

- 13 teams
- VisiON of team Osaka won
RoboCup 2004 H40 Penalty Kick Final
Team NimbRo @ Lisbon

Norbert Mayer, Thorsten Kramer, Michael Schreiber, Sven Behnke, Sven Seuken
Alpha and RoboSapien
Jörg Stückler, Jürgen Müller, Tobias Langner
Alpha

• 21 DOFs
  - 6 per leg,
  - 3 per arm,
  - 3 in the trunk
  - Geared DC motors
• 155cm, ~30kg
• Dummy head and hands
Mechanics

DC motor Faulhaber 3863, 3257 with 66:1 planetary gear and magnetic encoder

2 DOF joint

Carbon-composite material
Electronics

• Subnotebook as main computer
  - 1.35kg, 1.7GHz Pentium-M

• 11 microcontroller boards

• CAN bus

• NiMH batteries
  - 12/24V
  - High current

• DC-DC-converter
  - buffered
Microcontroller board

- **Motorola HCS12**
  - 128K flash, 8K RAM
  - 8 x PWM, 16 x A/D
  - 2 x CAN controller
- **2 x motor driver MC3486**
  - 35A max
  - 10A continuous
- **4 x 1A switches**
- **2 x instrument amplifier AD8221**
- **CAN, RS232**
- **3 x servo**
- **User interface**
  - 4 x LED
  - DIP
  - Beeper
Microcontroller Tasks

• **Motor control**
  - Pulse accumulation, reading of potentiometers
    -> current position, speed
  - Outer loop controls position @ 60Hz
  - Inner loop controls speed @ 120Hz
  - Output: PWM, turning direction

• **CAN communication**
  - 60Hz
  - State to PC
  - Target position, parameters from PC

• **Preprocessing of sensor readings**
  - Robust filtering
Sensors

- **Cameras**
  - Apple iSight uncompressed Firewire camera with wide-angle converter

- **Accerometers and gyros**
  - Accelerometer ADXL203
  - Gyroskope ADXRS150/300

- **Force sensors**
  - Strain gauge BLH FAE4-6257J
  - I.E.E. FSR

- **Motor encoders**
- **Potentiometers**
Attitude estimation

- Accelerometer cannot distinguish between gravity and other accelerations
- Gyro reports only rotational speed, need starting point for integration
- Offset must be calibrated, use longer-term accelerometer readings
Framework for behavior control

- Developed at FU Berlin
- Supports hierarchy of reactive behaviors
  - Time hierarchy (60Hz, 30Hz, 15Hz, ...)
  - Agent hierarchy (body-bodypart-joint)
  - Abstract interfaces
  - Complexity reduction through interaction constraints
- Logging of all variables
- 3D visualization
- ODE simulation
Third price @ RoboCup 2004 Freestyle Competition
Alpha’s Head

16 DOFs:
- 3 eyes
- 3 neck
- 4 eye brows
- 6 mouth
Multimodal Dialog System

- Face localization and tracking (OpenCV)
- Maintain list of closest persons
- Robust speech recognition (Novotec)
- Dialog management (FSM)
- Speech synthesis (Txt2Pho, MBROLA)
- Gaze control (saccades, smooth pursuit)
- Head direction control
- Animated mouth while speaking
Conversation with Alpha's Head
Outlook for Alpha

- Mimics, expression of emotions
- Integration of head and body
- Actuated hands
- Pointing gestures
- Use as museum guide
RoboSapien

- Toy robot, developed by M. Tilden, produced by WowWee
- 7 DOFs
- 3DOF Dynamic walking
- Augmented with Pocket
RoboSapien @ RoboCup 2004

- Third place in RoboCup 2004 Technical Challenge (one of two teams able to walk over a ramp)
- Humanoid Walk in our lab
- API downloadable (got slash-dotted)
Soccer with RoboSapien

- New version with arms and wide-angle lens
- Want to show 4 vs. 4 demo game at German Open 2005 (with Brainstormers Osnabrück)
- Computer vision, behavior control, Infrastructure
Field player and goalie
Dynamic Walking

- Starting from static stability
  - Zero-Moment-Point
  - Center of Pressure
- Starting from dynamic stability
  - Passive dynamic walking
    - Elegant
    - Energy efficient
    - Minimal actuation
  - Inverted pendulum
- Need both modes
Kondo robot KHR-1

- Japanese construction kit
- 17 Servos
  - 5 per leg,
  - 3 per arm,
  - head
- 34cm, 1.2kg
- RS232 interface
- Motion control software
- NiCd battery
Augmented Kondo

- Pocket PC + camera
- Behavior control @ 50Hz

- Walking implemented
- Working on automatic gait optimization
Toni

- **18 DOFs** (6 per leg, 3 per arm)
- Driven by servos
- **74cm, 2.2kg**
- Lightweight aluminum frame
- **3 ChipS12 boards**
- **CAN, RS232**
- Pocket PC + camera
- **167Hz control**
- Attitude sensors
- LiPoly batteries
Walking with 16.5cm/s @ 2Hz
Toes Joint
Omnidirectional Walking
Autonomous Ball Play
Outlook for Toni

• Force sensors, compass
• Smaller and larger versions for KidSize (<60cm) and MidSize league (60...180cm)
• Soccer: Kicking, self localization, ball control, instep, chest, …

July 13th - 19th,
Conclusions

• Complex integration task
• Weakest component determines performance
• Integrated system more than sum of parts
• Synergy effects:
  - Audio-visual speech recognition
  - Active perception
  - Perfect reconstruction of world not needed; percept must only be sufficient for behavior control
Challenges

- Artificial muscles
- Light-weight frames
- Soft covers
- Energy supply
- Efficient locomotion
- Robust control
- Managing complexity of high number of DOFs
- Multimodal perception
- Team coordination
Vision: Personal Robots

Personal Robots Make the 21st Century More Fun

Corporate Executive Vice President, Sony Corporation
President, Intelligent Dynamics Research Institute
Chairman, Sony Computer Science Laboratories, Inc.
Founder, ROBODEX

Engineer Toshitada Doi

„In thirty years I think it [the personal robot industry] will be bigger than the personal computer industry. We need to do more research, however, into movement but also into intelligence.“
Team NimRo

Staff:
- Dr. Maren Bennewitz,
- Jürgen Müller

Students:
- Felix Faber (Head control),
- Dominik Joho (Speech processing),
- Thorsten Kramer (Behavior control),
- Tobias Langner (Pocket PC),
- Julio Pastrana (Gait optimization),
- Michael Schreiber (Mechanics),
- Joachim Strach (Computer vision),
- Jörg Stückler (Simulation),
- Konstantin Welke (Behavior control),
- Rui Zhou (CAN flasher)

Other contributors:
- Alexander Kleiner (Simulation)
Questions
Demo in the hall.

RoboSapien  Kondo  Toni