CMRoboBits: Creating an Intelligent AIBO Robot

Paul E. Rybski

Thanks to: Prof. Manuela M. Veloso, Scott Lenser, Douglas Vail, Sonia Chernova

CORAL Research Group
School of Computer Science
Carnegie Mellon University
AIBO-Based Robotics/Al Course

Why AIBOs?
- Relatively inexpensive at ~$2,000
- Tremendous hardware/sensing in tiny package

Practicality / take-home message
- Provide students with a holistic view of mobile robots
- Demystify robot programming
- Show connections to computer science
  - Illustrate challenges of introducing explicit sensing and actuation in the real world!
- Overview of computer vision, embedded systems programming, behavioral control, kinematics, spatial reasoning, multi-robot cooperation

Robots are integrated intelligence:
- Sensing & perception
- Motion & kinematics
- Behavior & cognition
- Multi-robot cooperation & coordination

AIBO – a remarkable complete robotic platform… everything onboard
- How do you teach computer science on an embedded platform such as the AIBO?
- “Hacking the real world”
Sony AIBO Robot (ERS-210)

- 384 MHz MIPS processor
- 32MB RAM
- 176x144 pixel camera
- 3-axis accelerometers
- Stereo microphones
- Speaker
- 18 degrees of freedom
  - 3 DOF in each leg
  - 3 DOF in the head
  - 2 DOF in the tail
  - 1 DOF in the jaw
- 802.11b ethernet in PC slot
- Touch sensors
AIBO ERS-7

- 3-Axis Accelerometers
- Microphones
- LEDs
- CCD Camera 208x160 pixels
- IR Proximity Sensors
- Food Pads
- Wifi Card
- 576MHz MIPS CPU
- 64 MB RAM
The “Hook”
General Course Overview

- Behaviors
- Sensors and actuators
- Motion
- Vision
- Localization
- Multi-Robot Cooperation
- Learning
Behaviors as Functions

Define a function which triggers actions based on state...

...with the intention of ending up in a new desired state

Domain of state space (continuous or discrete)

Range of robot actions (including those of the team)

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Decompositional and Sequential Links in a Behavior FSM

Decompositional

Sequential

LIFTED STRAIGHT BEHAVIOR

AIBO lifted
AIBO tilted
AIBO back on ground
AIBO lifted

TILTED BEHAVIOR

AIBO lifted
AIBO tilted
AIBO back on ground

ON GROUND BEHAVIOR

WALK
TROT
RUN

SET LED-MIDDLE-LEFT
SET LED-MIDDLE-RIGHT

Tilted left
Tilted right
class Stop(object):
    def __call__(self, features, command):
        command.motion_cmd = Motion.MOTION_STAND_NEUTRAL
        command.head_cmd = Motion.HEAD_SCAN_MARKERS
        command.vx = 0
        command.vy = 0
        command.va = 0
        return (1.0, command)

fsm = FSM.FSM(['state1', ['state1', 'state2', 'state3']])
try:
    fsm.startLoop()
    while fsm.running:
        if fsm.state == 'state1':
            if some_reason:
                fsm.trans('state2', 'some reason')
                continue
            else:
                fsm.endLoop()
        elif fsm.state == 'state2':
            if another_reason:
                fsm.trans('state3', 'another reason')
                continue
            else:
                fsm.endLoop()
        elif fsm.state == 'state3':
            fsm.endLoop()
except FSMError, error:
    print 'FSM Error:', str(error)
    fsm.endLoop()
Sensors: Accelerometer

Robot standing

Robot held on left side, then rotated to upright, then rotated to right side down
The Motion Interface

Dynamic Walking Motion

Walk Parameters

Walk Engine

Static Frame-Based Motion

Motion Frames

Frame Interpolator
Motion

- Four-legged actuation for mobility
- Head motion for sensing and object manipulation
- Manipulation of objects (kicking) with all limbs

Climbing the Wall

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http://www.cs.cmu.edu/~coral

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Vision

- Single monocular camera
- Color-based image segmentation
  - All things of interest are classified by their colors
- Object detection and classification
  - Object distance and pose calculated from AIBO joint angles (flat world assumption)

CMVision2
Vision

Color segmentation based on YUV color space

Object models based on flat world assumption

Accurate vision in fixed environmental conditions
Playing Mastermind with AIBOs
Freespace and obstacles are stored as points. After 2 seconds, points are forgotten. Occupancy grid is created by sampling points in grid cells for every frame of video.
More AIBO Tricks

Visual Sonar

Scott Lenser and Manuela Veloso
Computer Science Department
Carnegie Mellon University

October 21, 2003
Localization

- Particle-filter based localization
- Unique landmarks placed around the field
- Quality of localization is based on number and quality of visual readings
- Teach basic probabilistic reasoning, modeling, and Bayesian filtering techniques
Localization
Navigating to a Goal

Combines goal pursuit with obstacle contour following to navigate around obstacles

Move directly towards goal if no obstacles block path.

If path is blocked, follow obstacle contour.

Stop obstacle following when straight-line vector to path becomes available.

Find Path to Goal: concave obstacle

Avoiding obstacles

Sample trajectory tracked with overhead camera
Multi-Robot Cooperation

- Communication
  - Using 802.11b
  - Must be robust to errors
- Cooperative motions
  - Synchronization through state machines
  - Global localization is critical for some tasks
Learning

- Taught mainly as an academic exercise
  - Methods for finding good values for complex parameter sets
- Examples of learning systems are discussed in lectures
- Final project allows some students to explore learning concepts

Walk learning movie
Insights

- Students took to the AIBOs very well
  - Actively installed the compilation tools on their own machines
- Software still requires an expert to maintain it
- Students discovered interesting ways to break software
  - Using Open-R to interact with hardware in strange ways
- C++ as a systems language has lots of gotchas
  - Pointers? What are these pointer things?
- Python is an excellent embedded behavior language
- Never could train students to properly unmount their memory sticks...
- Real-world issues brought out the best (worst?) in student creativity

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Multi-Robot Cooperation

Cooperative Bar Pushing
Jacob Kalberer and Jayesh Sureshchandra
Final Project
Fall 2005

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Instructors: Dr. Paul E. Rybski and Prof. Manuela Veloso
TAs: Juan Fasola and Matt Russo
AIBO Obstacle Course

The robot moves through an obstacle course changing gaits whenever a colored marker is observed.

Katie Chang and Ling Xu

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Teaching Assistants: Doug Vail, Nicholas Aiwazian
Further support: Sonia Chernova, Paul E. Rybski
Maze Learning

The robot traverses a maze with dead ends and then goes through a second time using the learned map to make the correct choices.

Sylvain Paillard, Abe Wong

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AIBO Tag

Two robots play a game of tag. They swap who is "it" by communicating over the wireless network.

Noah Falk and Joe Delfino

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AIBO Dance
Ritika Sanghi and Yash Patodia

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Further information...

Paul Rybski
- [http://www.cs.cmu.edu/~prybski](http://www.cs.cmu.edu/~prybski)
- prybski@cs.cmu.edu

CMRoboBits Course Page
- All course materials are available for download
  - More updates coming!!!
- [http://www.cs.cmu.edu/~robosoccer/cmrobobits](http://www.cs.cmu.edu/~robosoccer/cmrobobits)

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CORAL Research Page
- [http://www.cs.cmu.edu/~coral](http://www.cs.cmu.edu/~coral)

OpenR SDK
- [http://openr.aibo.com](http://openr.aibo.com)

RoboCup
- [http://www.robocup.org](http://www.robocup.org)