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Automation and Robotics
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Recently published articles

- A software modeling approach for the design and analysis of cooperative optimization systems
- Nature Inspired Cooperative Strategies for Optimization
- A new fuzzy linguistic approach to qualitative Cross Impact Analysis
- The role of cardinality and neighborhood sampling strategy in agent-based cooperative strategies for Dynamic Optimization Problems
- A centralised cooperative strategy for continuous optimisation: The influence of cooperation in performance and behaviour
- Exploring Innovative and Successful Applications of Soft Computing
- A Linguistic Approach to Structural Analysis in Prospective Studies
- Using knowledge discovery in cooperative strategies: two case studies
- On the Performance of Homogeneous and Heterogeneous Cooperative Search Strategies
Motivation

• Intelligent Environments are aimed at improving the inhabitants’ experience and task performance
  – Automate functions in the home
  – Provide services to the inhabitants

• Decisions coming from the decision maker(s) in the environment have to be executed.
  – Decisions require actions to be performed on devices
  – Decisions are frequently not elementary device interactions but rather relatively complex commands
    • Decisions define set points or results that have to be achieved
    • Decisions can require entire tasks to be performed
Automation and Robotics in Intelligent Environments

- Control of the physical environment
  - Automated blinds
  - Thermostats and heating ducts
  - Automatic doors
  - Automatic room partitioning

- Personal service robots
  - House cleaning
  - Lawn mowing
  - Assistance to the elderly and handicapped
  - Office assistants
  - Security services
Robots

• Robota (Czech) = A worker of forced labor
  From Czech playwright Karel Capek's 1921 play “R.U.R”
  (“Rossum's Universal Robots”)

• Japanese Industrial Robot Association (JIRA) :
  “A device with degrees of freedom that can be controlled.”
  – Class 1 : Manual handling device
  – Class 2 : Fixed sequence robot
  – Class 3 : Variable sequence robot
  – Class 4 : Playback robot
  – Class 5 : Numerical control robot
  – Class 6 : Intelligent robot
A Brief History of Robotics

• Mechanical Automata
  – Ancient Greece & Egypt
    • Water powered for ceremonies
  – 14\textsuperscript{th} – 19\textsuperscript{th} century Europe
    • Clockwork driven for entertainment

• Motor driven Robots
  – 1928: First motor driven automata
  – 1961: Unimate
    • First industrial robot
  – 1967: Shakey
    • Autonomous mobile research robot
  – 1969: Stanford Arm
    • Dextrous, electric motor driven robot arm

Maillardet’s Automaton
Unimate
Robots

- Robot Manipulators
  ![Robot Manipulators Image]

- Mobile Robots
  ![Mobile Robots Image]
Robots

- Walking Robots

- Humanoid Robots
Autonomous Robots

• The control of autonomous robots involves a number of subtasks
  – Understanding and modeling of the mechanism
    • Kinematics, Dynamics, and Odometry
  – Reliable control of the actuators
    • Closed-loop control
  – Generation of task-specific motions
    • Path planning
  – Integration of sensors
    • Selection and interfacing of various types of sensors
  – Coping with noise and uncertainty
    • Filtering of sensor noise and actuator uncertainty
  – Creation of flexible control policies
    • Control has to deal with new situations
Traditional Industrial Robots

- Traditional industrial robot control uses robot arms and largely pre-computed motions
  - Programming using “teach box”
  - Repetitive tasks
  - High speed
  - Few sensing operations
  - High precision movements
  - Pre-planned trajectories and task policies
  - No interaction with humans
Problems

• Traditional programming techniques for industrial robots lack key capabilities necessary in intelligent environments
  ▪ Only limited on-line sensing
  ▪ No incorporation of uncertainty
  ▪ No interaction with humans
  ▪ Reliance on perfect task information
  ▪ Complete re-programming for new tasks
Requirements for Robots in Intelligent Environments

• Autonomy
  – Robots have to be capable of achieving task objectives without human input
  – Robots have to be able to make and execute their own decisions based on sensor information

• Intuitive Human-Robot Interfaces
  – Use of robots in smart homes can not require extensive user training
  – Commands to robots should be natural for inhabitants

• Adaptation
  – Robots have to be able to adjust to changes in the environment
Robots for Intelligent Environments

- **Service Robots**
  - Security guard
  - Delivery
  - Cleaning
  - Mowing

- **Assistance Robots**
  - Mobility
  - Services for elderly and People with disabilities
Autonomous Robot Control

• To control robots to perform tasks autonomously a number of tasks have to be addressed:
  – Modeling of robot mechanisms
    • Kinematics, Dynamics
  – Robot sensor selection
    • Active and passive proximity sensors
  – Low-level control of actuators
    • Closed-loop control
  – Control architectures
    • Traditional planning architectures
    • Behavior-based control architectures
    • Hybrid architectures
Modeling the Robot Mechanism

- Forward kinematics describes how the robots joint angle configurations translate to locations in the world.
- Inverse kinematics computes the joint angle configuration necessary to reach a particular point in space.
- Jacobians calculate how the speed and configuration of the actuators translate into velocity of the robot.
Mobile Robot Odometry

• In mobile robots the same configuration in terms of joint angles does not identify a unique location
  – To keep track of the robot it is necessary to incrementally update the location (this process is called odometry or dead reckoning)

\[
(x)_{t+\Delta t} = (x)_t + \begin{pmatrix} v_x \\ v_y \\ \theta \end{pmatrix} \Delta t
\]

• Example: A differential drive robot

\[
v_x = \cos(\theta) \frac{r(\dot{\phi}_L + \dot{\phi}_R)}{2}, \quad v_y = \sin(\theta) \frac{r(\dot{\phi}_L + \dot{\phi}_R)}{2}
\]

\[
\sigma = \frac{r}{d} (\dot{\phi}_L - \dot{\phi}_R)
\]
Actuator Control

• To get a particular robot actuator to a particular location it is important to apply the correct amount of force or torque to it.
  – Requires knowledge of the dynamics of the robot
    • Mass, inertia, friction
    • For a simplistic mobile robot: \( F = m a + B v \)
  – Frequently actuators are treated as if they were independent (i.e. as if moving one joint would not affect any of the other joints).
  – The most common control approach is PD-control (proportional, differential control)
    • For the simplistic mobile robot moving in the x direction:
      \[
      F = K_P (x_{desired} - x_{actual}) + K_D (v_{desired} - v_{actual})
      \]
Robot Navigation

• Path planning addresses the task of computing a trajectory for the robot such that it reaches the desired goal without colliding with obstacles
  – Optimal paths are hard to compute in particular for robots that can not move in arbitrary directions (i.e. nonholonomic robots)
  – Shortest distance paths can be dangerous since they always graze obstacles
  – Paths for robot arms have to take into account the entire robot (not only the endeffector)
Sensor-Driven Robot Control

• To accurately achieve a task in an intelligent environment, a robot has to be able to react dynamically to changes in its surrounding
  – Robots need sensors to perceive the environment
  – Most robots use a set of different sensors
    • Different sensors serve different purposes
  – Information from sensors has to be integrated into the control of the robot
Robot Sensors

- Internal sensors to measure the robot configuration
  - Encoders measure the rotation angle of a joint
  - Limit switches detect when the joint has reached the limit
Robot Sensors

• Proximity sensors are used to measure the distance or location of objects in the environment. This can then be used to determine the location of the robot.
  – Infrared sensors determine the distance to an object by measuring the amount of infrared light the object reflects back to the robot
  – Ultrasonic sensors (sonars) measure the time that an ultrasonic signal takes until it returns to the robot
  – Laser range finders determine distance by measuring either the time it takes for a laser beam to be reflected back to the robot or by measuring where the laser hits the object
Robot Sensors

• Computer Vision provides robots with the capability to passively observe the environment
  – Stereo vision systems provide complete location information using triangulation

  – However, computer vision is very complex
    • Correspondence problem makes stereo vision even more difficult
Uncertainty in Robot Systems

- Robot systems in intelligent environments have to deal with sensor noise and uncertainty
  - Sensor uncertainty
    - Sensor readings are imprecise and unreliable
  - Non-observability
    - Various aspects of the environment cannot be observed
      - The environment is initially unknown
  - Action uncertainty
    - Actions can fail
    - Actions have nondeterministic outcomes
Explicit reasoning about Uncertainty using Bayes filters:

\[ b(x_t) = \eta \int p(x_t | x_{t-1}, a_{t-1}) b(x_{t-1}) \, dx_{t-1} \]

Used for:
- Localization
- Mapping
- Model building
Deliberative Robot Control Architectures

- In a deliberative control architecture the robot first plans a solution for the task by reasoning about the outcome of its actions and then executes it.

Control process goes through a sequence of sensing, model update, and planning steps.
Behavior-Based Robot Control Architectures

- In a behavior-based control architecture the robot’s actions are determined by a set of parallel, reactive behaviors which map sensory input and state to actions.
Complex Behavior from Simple Elements: Braitenberg Vehicles

• Complex behavior can be achieved using very simple control mechanisms
  – Braitenberg vehicles: differential drive mobile robots with two light sensors

  “Coward”  “Aggressive”  “Love”  “Explore”

• Complex external behavior does not necessarily require a complex reasoning mechanism
Behavior-Based Architectures: Subsumption Example

- Subsumption architecture is one of the earliest behavior-based architectures
  - Behaviors are arranged in a strict priority order where higher priority behaviors subsume lower priority ones as long as they are not inhibited.
Subsumption Example

- A variety of tasks can be robustly performed from a small number of behavioral elements

© MIT AI Lab
http://www-robotics.usc.edu/~maja/robot-video.mpg
Reactive, Behavior-Based Control Architectures

• Advantages
  – Reacts fast to changes
  – Does not rely on accurate models
    • “The world is its own best model”
  – No need for replanning

• Problems
  – Difficult to anticipate what effect combinations of behaviors will have
  – Difficult to construct strategies that will achieve complex, novel tasks
  – Requires redesign of control system for new tasks
Hybrid Control Architectures

- Hybrid architectures combine reactive control with abstract task planning
  - Abstract task planning layer
    - Deliberative decisions
    - Plans goal directed policies
  - Reactive behavior layer
    - Provides reactive actions
    - Handles sensors and actuators
Hybrid Control Policies

Task Plan:

Behavioral Strategy:
Example Task:
Changing a Light Bulb
Traditional Human-Robot Interface: Teleoperation

- Remote Teleoperation: Direct operation of the robot by the user
  - User uses a 3-D joystick or an exoskeleton to drive the robot
    - Simple to install
    - Removes user from dangerous areas
  - Problems:
    - Requires insight into the mechanism
    - Can be exhaustive
    - Easily leads to operation errors
Example: Minerva the Tour Guide Robot (CMU/Bonn)
Learning Sensory Patterns

- **Learning to Identify Objects**
  - How can a particular object be recognized?
    - Programming recognition strategies is difficult because we do not fully understand how we perform recognition.
  - Learning techniques permit the robot system to form its own recognition strategy.
  - Supervised learning can be used by giving the robot a set of pictures and the corresponding classification:
    - Neural networks
    - Decision trees

Chair
Example: Reinforcement Learning in a Hybrid Architecture

- Policy Acquisition Layer
  - Learning tasks without supervision
- Abstract Plan Layer
  - Learning a system model
  - Basic state space compression
- Reactive Behavior Layer
  - Initial competence and reactivity
Example Task: Learning to Walk
Example: Learning to Walk
Conclusions

- Robots are an important component in Intelligent Environments
  - Automate devices
  - Provide physical services
- Robot Systems in these environments need particular capabilities
  - Autonomous control systems
  - Simple and natural human-robot interface
  - Adaptive and learning capabilities
  - Robots have to maintain safety during operation
- While a number of techniques to address these requirements exist, no functional, satisfactory solutions have yet been developed
  - Only very simple robots for single tasks in intelligent environments exist
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- A Global Colloquium on Artificial Intelligence
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