Introduction to Robotics

A Modern Approach
Arnoud Visser
The word *robot* was introduced in 1920 in a play by Karel Capek called R.U.R.
The Robot

A robot is an artificial worker, which can replace a human worker.
Industrial Robots

• Industrial robots have replaced many human workers for tasks which are:
  – high repetitive
  – well structured
  – i.e. factory jobs
Robotic Evolution

- telemanipulators
- planetary rovers
- manufacturing
- Vision
- AI Robotics
- telesystems
- Industrial Manipulators

Timeline:
- 1960
- 1970
- 1980
- 1990
- 2000
AI Robots

AI Robots are physically situated *agents* with:

- Knowledge representation
- Learning
- Planning and problem solving
- Search and Inference
- Vision
- Understanding natural language
Physical situated agent

An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators†

The physical grounding hypothesis

‘To build an intelligent system it is necessary to have its representations grounded in the physical world.’

i.e.:

‘The world is its own best model; its always exactly up to date and contains always every detail there is to know.’ †

Introduction to Classical Robotics

Model based

† Summary of material covered by Leo Dorst’s syllabus
Robot arms

- Traverse stroke (travel)
- Vertical stroke (elevation)
- Horizontal stroke (reach)
- Rectangular workspace
- Vertical swing around shoulder
- Horizontal stroke (r)
- Sweep around waist (θ)
- Cylindrical workspace
- Minimum horizontal reach
- Maximum horizontal reach
- Horizontal reach

AIMA p. 904-905
Controllable Degrees of Freedom

![Diagram showing configuration space and task space with controllable degrees of freedom.

- **Configuration Space**: A grid with rows labeled 'Angle of Elbow' and columns labeled 'Angle of Shoulder'. Each cell represents a possible configuration of the arm.

- **Task Space**: A diagram showing the arm's movement, with labels for 'Elbow ($\theta_2$) = 60°' and 'Shoulder ($\theta_1$) = 120°'.

- **Angle Measure**: 0°
Planning to move

- Cell decomposition
Several cost models possible

- Value Iteration

AIMA p. 920
Minimal movement of hand
Same configuration, more obstacles
Mixed cells

- Discretization Error

AIMA p. 920
Potential Field

- Other cost function!
Skeleton Methods

- Other representation of free space

AIMA p. 922
Sensors

**Range finders:**
- sonar (land, underwater), laser range finder, radar (aircraft),
- tactile sensors, GPS

**Imaging sensors:**
- cameras (visual, infrared)

**Proprioceptive sensors:**
- shaft decoders (joints, wheels),
- inertial sensors, force sensors, torque sensors
Uncertainty

- Both uncertainty in observations and in movements
- Reasoning over time and uncertainty
- States, transitions, observations & beliefs
- Causal versus Diagnostic Reasoning

P(seems open | is open) versus P(is open | seems open)
25.3 Robotic Perception

25.5 Planning uncertain movements
Probabilistic Robotics†

Robotic Paradigms

1976 — 1986
- **Model-Based Robotics**
  - Full model, no sensor data
  - Focus on motion planning

1986 — 1996
- **Behavior-Based Robotics**
  - No model, entirely data-driven
  - Focus on environment feedback

1996 — 2006
- **Probabilistic Robotics**
  - Uncertain model, noisy data
  - Integration of data and model

Introduction to AI Robotics

Behavior Based

Perception - Action Cycle

Perception

Real world

Model of the world

Action
Sense-Plan-Act

- **Sense**
  - “Translate” physical properties to electrical (digital) signals.
  - Sensor: Input of the system

- **Plan**
  - Attempt to solve a problem (with a purpose)
  - Needs (complete) model of the world

- **Act**
  - “Translate” electrical (digital) signals to other physical properties.
  - Actuator: Output of the system
Hierarchical approach
Reactive Approach

AIMA p. 932-933

Diagram:

- Sense
- Plan?
- Act

Flowchart:

Sense → Plan? → Act
Hybrid / deliberative approach

- Planning is making decisions autonomously!

AIMA p. 933-934
Remote Control

- you control the robot
- you can view the robot and its relationship to the environment
- *operator isn’t removed from scene, not very safe*
Example: Bomb squad
Teleoperation

- you control the robot
- you can only view the environment through the robot’s eyes
- don’t have to figure out AI
- Depending on display: Telepresence
Example: Micro Aerial Vehicle
semi-autonomy

- human is involved, but routine or "safe" portions of the task are handled autonomously by the robot
- Shared Control/ Guarded Control
  - human initiates action, interacts with remote by adding perceptual inputs or feedback, and interrupts execution as needed
  - robot may "protect" itself by not bumping into things
- Traded Control
  - human initiates action, does not interact
- *human doesn’t have to do everything*
Example: semi-autonomy
Autonomy in Robotics

- **Use Robots**
  - when humans cannot or do not want do do it

- **In Teleoperations**
  - humans do not act, but are needed all the time
  - cognitive fatigue, high comms bandwidth, long delays, and many:one human to robot ratios

- **Semi-autonomy**
  - tries to reduce fatigue, bandwidth by delegating portions of the task to robot
  - human only acts when needed
Behavior-based approach

The Turning Point in Robotics

Behavior-Based Robotics, Brooks 1986


AIMA p. 932-933
Bio-inspired

Level 1: What is the phenomena?

Level 2: How is it represented?

Level 3: How is it implemented?

for (i=0; i<n; i++)
Why look at biology?

- No world model (so no frame problem)
  - "The world is its own best representation" [Gibson]
- Proof of principle
  - It is possible
- Copying the "organization"
  - Shows how it can be done
Ethology: Coordination and Control of Behaviors

1973 Nobel Prize for Physiology or Medicine:
Karl Von Frisch, Konrad Lorenz and Nikolaas Tinbergen
Behaviors

Types of behaviors

- Reflexive
  - stimulus-response, often abbreviated S-R
- Reactive
  - learned or "muscle memory"
- Conscious
  - deliberately stringing together

Warning: In robotics "reactive behavior" often means purely reflexive, and reactive behaviors are referred to as "skills".
Example of reflexive behavior

- Arctic terns live in the Arctic (black, white, gray environment, some grass) but adults have a red spot on beak
- When hungry, baby pecks at parent’s beak, who regurgitates food for baby to eat
- How does it know its parent?
  - It doesn’t! It just goes for the largest red spot in its field of view (e.g., ethology student)
  - Only red thing should be an adult tern
  - Closer = large red
Feeding behavior

RED (external)
HUNGRY (internal)

Present?

YES
Feeding Behavior

PECK AT RED

NO
Do Something Else
Behavior of Life

OTHER LIVING THING (external)

Larger?

YES FLEE

NO

Smaller?

YES EAT

NO

MATE
General principles

Ethology
- All animals possess a set of behaviors
- Releasers for these behaviors rely on both internal state and external stimulus
- Perception is filtered; perceive what is relevant to the task
- Some behaviors and associated perception do not require explicit knowledge representation

Robotics
- Individual robots must survive, not species
- Must be able to predict emergent behaviors
- Not clear how to learn quickly
- Robots need more alternative perceptual schemas since poorer understanding of the environment
Subsumption architecture  
(Brooks 1986)
Subsumption philosophy

- Modules should be grouped into layers of competence
- Modules in a higher lever can override or subsume behaviors in the next lower level
  - Suppression: substitute input going to a module
  - Inhibit: turn off output from a module
- No internal state in the sense of a local, persistent representation similar to a world model.
- Architecture should be taskable: accomplished by a higher level turning on/off lower layers
Level 0: avoid collision
Level 1: wander

**WANDER**

- PS
  - encoders

- MS
  - WANDER
  - AVOID

**AVOID**

- MS
  - modified heading
  - What would Inhibition do?

- PS
  - FEEL FORCE
  - RUN AWAY

**Note sharing of Perception, fusion**

- SONAR
  - polar plot

- COLLIDE

- TURN
  - heading
  - encoders

- FORWARD
  - halt
Level 2: follow corridor
The result: Finite State Automata
FSM is a simplification of the world

Searching for correlations in data

Spatial Knowledge in Robotics†

- Localization
  Where am I?  (current location)

- Mapping
  Where have I been?  (past locations)

- Exploration
  Where am I going?  (future locations)

† Robin R. Murphy, ‘Introduction to AI Robotics’, MIT Press, 2000
Probabilistic Robotics†

An *agent* is anything that can be viewed as *perceiving* its *environment* through *sensors* and *acting* upon that environment through *actuators*†

Theory of multiple intelligences

- linguistic,
- logical-mathematical,
- spatial,
- bodily-kinesthetic,
- naturalistic,
- musical,
- interpersonal,
- intrapersonal.  

Anthropic principle

To replace a human worker, a robot needs the equivalent of:

- Human knowledge
- Human rational
- Human perception
- Human actuators
- Human communication
Human actuators

† Asimo, Honda’s Humanoid robot, Commercial 2006

AIMA p. 902
Robotics plays a central role in AI

- Integration platform for many areas of AI
- Benchmark platform for progress in AI
- Embodiment is a prerequisite for intelligence
- Future of AI is projected on robotics†

† 50 years Artificial Intelligence Symposium, Bremen.
Synergistic Intelligence

† Hiroshi Ishiguro ‘2006-2056 Projects and Vision in Robotics’, 50 years Artificial Intelligence Symposium, Bremen.
Developments in humanoids go fast.
Uncanny valley [Mori et al. '97]

Familiarity

Uncanny valley

Similarity

100%

Human

Adult android

Moving corpse

Child android

Doll

Toy robot
Ishiguro’s Androids

- Child (Repliqee R1)
- Adult (Repliqee Q2)
- Ishiguro (Gemenoid)
Cybernetics

• Can we use technology to upgrade humans?
• Can we use organic brains in robots?
Conclusion

- Robotics plays a central role in AI
- Embodiment is a prerequisite for intelligence

The chess-playing Turk defeated Napoleon in 1769