Autonomous Robotics: Action, Perception and Cognition

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What comes to your mind when you hear the word “robot”

Google search “robot” (10 apr 2018)
=> Humanoids (or anthropomorphomorphic) robots
=> vehicles
fundamentally, all factory automatization is a form of robotics: “programmable” machines...

in reality, industrial robots are much more common today than humanoids or autonomous vehicles
examples of robots

other than humanoid or industrial
simple, single-task autonomous vehicles

Figure 5.5. Examples of service robots.

[photo credits: WTEC final report 2006]
some of our own (older) autonomous vehicles
outdoor vehicles

Figure 2.1. NASA Mars Rover (NASA Jet Propulsion Laboratory (JPL)).

Another example of a hostile and hazardous environment where robotic vehicles are essential tools of work and exploration is the undersea world. Human divers may dive to a hundred meters or more, but pressure, light, currents and other factors limit such human exploration of the vast volume of the earth’s oceans. Oceanographers have developed a wide variety of sophisticated technologies for sensing, mapping, and monitoring the oceans at many scales, from small biological organisms to major ocean circulation currents. Robotic vehicles, both autonomous and ROV types, are an increasingly important part of this repertoire, and provide information that is unavailable in other ways. Figure 2.2 shows an autonomous underwater vehicle (AUV) called ASTER under development at Institut Français de Recherche pour l’Exploitation de la Mer (IFREMER), the French National Institute for Marine Science and Technology. ASTER will be used for coastal surveys of up to 3,000 meters in depth and is capable of carrying a wide variety of instrumentation for physical, chemical, and biological sensing and monitoring. In United States research, the evolution of remotely operated vehicles for deep ocean exploration enabled the discovery of the sunken Titanic and the ability to explore that notable shipwreck.

In addition to space and oceans, there are many applications where human presence is hazardous. Nuclear and biological contamination sites must often be explored and mapped to determine the types and extent of contamination, and provide the basis for remediation. Military operations incorporate many different autonomous and remotely operated technologies for air, sea, and ground vehicles. Increasingly, security and defense systems may use networks of advanced mobile sensors that observe and detect potential events that may pose threats to populations.

In a second class of applications, robotic vehicles are used in routine tasks that occur over spaces and environments where machine mobility can effectively replace direct human presence. For example, large-scale agriculture requires machines to cultivate, seed, irrigate, and harvest very large areas of terrain. The ability to track an autonomous vehicle using global positioning systems (GPS), sensing the soil and plant conditions in the field, encourages the implementation of robotic vehicles for agricultural or field applications. Figure 2.3a shows an example of an agricultural robotic vehicle under development in the United States. Figure 2.3b shows a large autonomous mining haul truck developed in Australia.

In a third class of applications, robotic vehicles occur in the support of personal assistance, rehabilitation, and entertainment for humans. A robotic wheelchair may provide mobility for a human who would otherwise not be able to move about. The integration of sensors, computational intelligence, and improved power systems have made such personal robotic aides increasingly capable and practical for everyday use. An example of a wheelchair that utilizes emerging robotic technologies for guidance and balance is shown in Figure 2.4. More details on medical robotics and robotic aids to the handicapped will be described in Chapter 6.

Other examples of such personal aides include vehicles that support elderly care through feeding, household tasks, and emergency notification. Many daily household tasks may benefit from enhanced mobile robotics, and there are rapid commercial developments of vacuum cleaners and lawn mowers that utilize advanced sensor and navigation systems. Also, advanced entertainment systems will incorporate robotic vehicles including locomotion of humanoids and biomimetic pets that entertain and provide interactive companions. The Japanese development of humanoids and robotic pets with sophisticated locomotion systems, as shown in Figure 2.5, is a major topic of this international comparative study. More detailed examples of personal and entertainment robotic vehicles will be described in Chapter 5, and of humanoid robots in Chapter 4.
cars: autonomous driving
Figure C.58. The walking machines built by Dillmann’s group.
biologically inspired robotics
snakes, crawlers, climbers

Figure C.56. Mobile robot platforms in Dillman’s laboratory. Two SwissLog products are shown on the extreme right.

Pipe Inspection Robots

Prof. Dillmann’s lab has developed several articulated, snake-type robots for pipeline inspection. Some are now commercially available and used to inspect water pipes and oil pipelines (including the Alaska pipeline).

Figure C.57. Inspection robot.

Current work is concentrated on enabling the system to work in an unstructured environment. A multi-articulated system with six links will be used for inspection tasks in sewer pipelines.

Legged Locomotion

There are labs dedicated to the development of control systems for four- and six-legged robots, as well as bipeds. The emphasis appears to be in the application of artificial muscles (McKibben-type muscles with a rubber shield), reduction of size and weight, and joint design. Historically, they have fabricated several of the Lauron-type six-legged machines usually associated with Friedrich Pfeiffer at the Technical University of Munich (TUM). Apparently there has been a long-term cooperative effort between the two labs.

Networked Robots

Networked robots exploit the efficiency that is inherent in parallelism. They can also perform independent tasks that need to be coordinated (for example, fixturing and welding) in the manufacturing industry.

Networked robots also result in improved efficiency. Tasks like searching or mapping, in principle, are performed faster with an increase in the number of robots. A speed-up in manufacturing operations can be achieved by deploying multiple robots performing operations in parallel, but in a coordinated fashion. Perhaps the biggest advantage to using the network to connect robots is the ability to connect and harness physically-removed assets. Mobile robots can react to information sensed by other mobile robots in the next room. Industrial robots can adapt their end-effectors to new parts being manufactured up-stream in the assembly line. Human users can use machines that are remotely located via the network. (See Fig. 7.3.)

The ability to network robots also enables fault-tolerance in design. If robots can in fact dynamically reconfigure themselves using the network, they are more tolerant to robot failures. This is seen in the Internet where multiple gateways, routers, and computers provide for a fault-tolerant system (although the Internet is not robust in other ways). Similarly, robots that can plug and play can be swapped in and out, automatically, to provide for a robust operating environment.

Finally, networked robots have the potential to provide great synergy by bringing together components with complementary benefits and making the whole greater than the sum of the parts.

Applications for networked robots abound. The U.S. military routinely deploys unmanned vehicles that are reprogrammed remotely based on intelligence gathered by other unmanned vehicles, sometimes automatically. The deployment of satellites in space, often by astronauts in a shuttle with the shuttle robot arm, requires the coordination of complex instrumentation onboard the space shuttle, human operators on a ground station, the shuttle arm, and a human user on the shuttle. Home appliances now contain sensors and...
2. Robotic Vehicles

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Field Robotics

Robotic vehicles developed for both military and space applications are intended for use in rough terrain, that is, without roads or cleared areas. In this context, the experience of off-road robotic vehicles in the U.S. has also provided a basis for research in field robotics, the application of robotic vehicles to other unstructured domains, such as agriculture, mining, construction, and hazardous environments. In addition, U.S. industrial companies active in these areas have invested in prototype developments for these applications. Figure 2.3 is an example of these prototype vehicles.

Undersea Robotics

The United States has supported research in several different types of applications of underwater vehicles. These include:

a. Military and Defense Applications

As described in Military and Defense Systems, U.S. defense technologies have included many fundamental prototypes and products that provide both ROV and AUV technology for the military. Figure 2.9 shows several of these vehicles.
b. Coastal Security and Environmental Monitoring Systems

AUV systems may be used as surveillance and observance of systems with both defense and environmental implications. Figure 2.10 shows an overview of the Autonomous Oceanographic Sensor Network (AOSN) systems, deployed as an experiment at the Monterey Bay Aquarium Research Institute (MBARI) in California, which integrate many different robotic and sensor resources.

c. Scientific Mission and Deep Ocean Science

AUV and ROV technologies are the only means to actively explore large portions of the ocean volume. The study of ocean currents, ocean volcanoes, tsunami detection, deepsea biological phenomena, and migration and changes in major ecosystems are all examples of topics that are studied with these systems. Several of the major scientific laboratories in the world are located in the U.S. and are leaders in these fields. A new project, HROV, is funded by the National Science Foundation (NSF) to develop a new hybrid remotely operated vehicle for underwater exploration in extreme environments, capable of operation to 11,000 meters depth as shown in Figure 2.11.

Figure 2.2. IFREMER ASTER autonomous underwater vehicle.

Figure 2.11. HROV (Hybrid ROV) project (Johns Hopkins University (JHU) and Woods Hole (WHOL), U.S.).
airborne robots
robotic manipulators, hands

Figure 4.10. Dexterous arms at DLR, NASA and UMASS.
some of our own robotic manipulators
mobile robot manipulators

Figure C.28. Dexterous arm on mobile base, opening door (left), robot passing through doorway (right).
our own mobile robot manipulator

autonomous robotics

- *auto-nomos*: giving laws to oneself

- minimally: autonomous robots generate behavior based on sensory information obtained from their own on-board sensors

- in contrast to industrial robots that are programmed in a fixed and detailed way
but: even an industrial robot uses autonomous control to reach its programmed goals…

=> autonomy is expected to go beyond control, include decisions=qualitative change of behavior

- e.g. avoid obstacle to the left vs. to the right
- e.g., reach for one object rather than another
autonomous robotics

but: we do not expect autonomous robots to just do whatever “they want”… we expect to give them “order”
autonomous robotics

autonomy as a “programming interface”:

give instructions to a robot at a high level, in regular human language and gesture in a shared environment…

…and let the autonomous robot deal with the “details” of how to achieve goals
why autonomous robots?
why autonomous robots?

- asked my then 18 year old son…
  - to clean up, to serve drinks
  - but they are just generally cool too..
  - .. (after some hesitation)… in the military
toy/entertainment/animation

including therapy (autism)
assistance robotics

🔹 at home, in the work place
🔹 collaborate with human users
autonomous vehicles

…. well, for autonomous transport…

[Amazon robotized warehouse]
military, fire fighting, rescue

-the “ideal” application because desire to remove human agent from the scene is consensual ...

much research
may a military robot decide autonomously to shoot

.... navy ships do that already...

may a autonomous car decide between avoiding a pedestrian and preventing danger for car occupants?

fundamental problem: off-loading decisions from user to designer ...
autonomous robotics as a “playground” of research
autonomous robotics as a “playground” of research

- modern engineering models systems, treating the remainder stochastically…. autonomous robotics act in natural environments that are difficult to model

- autonomous robotics: highly interdisciplinary

- modern engineering uses modular design that limits the range over which modules interact/interfere… autonomous robotics: requires system integration
state of the art: current explosion

- through maturation of technology
- fast computation makes approach real-time that used to be not viable
- laser range finder
- modern software engineering facilitates programming
- … many detailed and specific improvements
what is entailed in designing an autonomous robot?

- sensors
- signal processing, digitization
- perception: estimation, detection, classification
- action planning
- communication, data security
- optimal control, control
- mechanics, actuators

=> an interdisciplinary task
4 core problems/challenges

- perception
- interacting with humans
- movement generation
- background knowledge
(I) perception

- no autonomy without perception
- main channel: visual perception
what is perception?
what is perception?

- we do not perceive the stimulus but the world and meaning

- seeing is active:
  - bring objects into the attentional foreground
  - see to answer questions
what is perception?

- attention
- segment
- recognize (invariantly)
- estimate (pose)
(2) interaction with humans

- in part a problem of perception as well...
- including perceptually grounding language
  - e.g., “the red cup to the left of the green cup“ …
research issues

- perceptually grounding language
- intention perception
- gesture recognition
- joint attention
- dialogue management
- emotion recognition
(3) back-ground knowledge

- implicit knowledge how the world works
  - how to open a door
  - that milk is in the fridge
  - how to grasp a glas vs. a cup vs. a spoon
  - how to grasp an object to achieve a particular goal
  - to clear space before moving something to a new place…

John Searle call this “background”
(knowledge, skills)
“background” is where the traditional approach to artificial intelligence was positioned

- knowledge bases
- reasoning
- action planning
- architectures
behavior based robotics / behavioral organization
special solutions designed/programmed “by hand”

autonomous learning from experience… largely unsolved

analogy with human nervous system whose structure reflects “knowledge” about how the world works…
(4) movement generation

- classical approach
  - motion planning based on precise world models
  - using optimal control to address control problems…

- but:
  - high demands on perception and on modeling of plant/objects
  - unclear if it works for soft actuation for safe interaction with humans
  - need for flexible, human like movement and movement sequences
research

- exploit analogies with human movement coordination, movement primitives
- exploit analogy with muscle: soft visco-elastic actuators
autonomous robotics inspired by analogy to human movement

- learning from how human movement is organized: properties, principles

=> an analogy robotics/organism at a more abstract level than in “neural dynamics”
Rough plan of course

- [dynamical systems tutorial]
- attractor dynamics approach to motion planning: vehicles
- robot arms: kinematics, attractor dynamics approach to reaching movements
- coordination and timing
- sequence generation
- probabilistic thinking, planning as inference