UNIT V AI AND OTHER RESEARCH TRENDS IN ROBOTICS

5.1 APPLICATION OF MACHINE LEARNING TO ROBOTICS

In recent years there has been an increasing interest in applying machine learning techniques to robotics. The applications are manipulator as well as mobile system tasks. The learning techniques used range from rote learning and inductive learning algorithms over analogical reasoning to Explanation Based Learning (EBL) and Case Based Learning (CBL).Besides these symbolic approaches considering mainly cognitive aspects of a robot control system
there are numerous works on using neural networks, reinforcement learning and genetic algorithms in robotics.

5.1.1 Applying ML to Robotics

In contrast to typical industrial automation systems an autonomous robot should be able to react to unexpected, uncertain and/or unknown events by parameter adaptation or additional planning activities. Thus, an autonomous system should be able to act in environments which are not perfectly modelled or where no a priori models are given at all, i.e. in applications where nowadays a telerobotic system could at most be used. We add to this definition the robot's ability to learn from its own experience and through human guidance.

One important reason for the limitations of today's robots lies in the enormous programming effort for even simple tasks or -if teach-in techniques are used - in the inflexibility and non-reusability of the programs.

Considering these aspects of autonomous systems the investigation of ML-techniques in robotics can help to accomplish the following principal tasks:

- ML as a programming tool for robotics applications (e.g. programming by showing)
- ML as a tool for the development and refinement (e.g. adaptation) of knowledge bases for autonomous robots (i.e. by using experience and experiments)
- ML for the stepwise transfer from telerobotic systems to semi-autonomous and further to autonomous behavior (comprises aspects of task 1 and 2)

5.1.2 Possible applications of ML to robotics

1. ***World model and elementary (sensor-based) actions***

- Learning of object properties (e.g. mass distribution, stable positions, geometry)
- Exploration of the current world (e.g finding known or prototypically represented objects, determining obstacles)
- Learning of elementary (sensor-based) actions in the world (e.g. collision-free paths, macro-trajectories, hand-eye coordination, effects of actions)
- Learning of elementary (sensor-based) actions with objects (e.g. reactive execution of a joining task, manipulation of an object)
- Optimization and refining of certain actions (e.g.trajectories)
- Learning to recognize/classify states in the internal world model

2. ***Sensors***

- Learning of classifiers for objects based on image data
- Learning of sensor strategies/plans, i.e. how to monitor an action to ensure the correct execution or how to determine certain states of the real world

3. ***Error analysis***

    - Learning of error recognition, error diagnosis and error repairing rules

4. ***Planning***

- Improvement (speed-up) of the planning module (e.g. planning macros, control rules)
- Learning of domain knowledge (e.g. general planning rules, orders that have to be taken into account in assembly applications)
- Learning of action rules or plans, i.e. how to solve a (sub)task in principle
- Learning of couplings between typical task classes and related action plans (e.g. generalized action plan for a set of tasks)
- Learning at the task level (e.g. which geometrical arrangements/action plans satisfy certain functional specifications.

The learning goals given above can be tackled by one single or a mixed approach of the three learning modes:

1. **Supervised**: A user acts as a teacher of the system, e.g. by typing input, by using a master-slave or a telerobotic system, or by solving the problem by his own;

2. **Semi-supervised**: The system plans experiments and executes them or formulates hypotheses, and a user criticizes/comments them;

3. **Unsupervised:** The system makes implicit knowledge an explicit one and plans experiments which can be criticized by itself.

5.1.3 System Architecture

Three main modules are used for acquiring object and action knowledge using visual and tactile sensing facilities.

- Learning of generic object descriptions (visually)
- Learning of static and dynamic object properties (tactile & visually)
- Learning of action rules for manipulation of the objects

While the first and second component are mainly working in unsupervised mode, action rules are acquired either by unsupervised generalization or through supervised learning by analyzing user actions.Figure 1 gives an overview of the architecture.

The system consists of

(1) A set of knowledge units, each consisting of a set of boards which store facts belonging to a semantic unit of knowledge (e.g. a board for facts of one object, of one planning subgoal, of one experiment), and an agent responsible for the interpretation of facts on instantiated boards with adequate learning strategies.

(2) A set of channels which pass information from one board to interested other boards. A knowledge unit receives all possibly interesting hypotheses. In the case of a request for certain facts by one agent these channels are also responsible for routing the request to knowledge units that might be able to give an appropriate answer.

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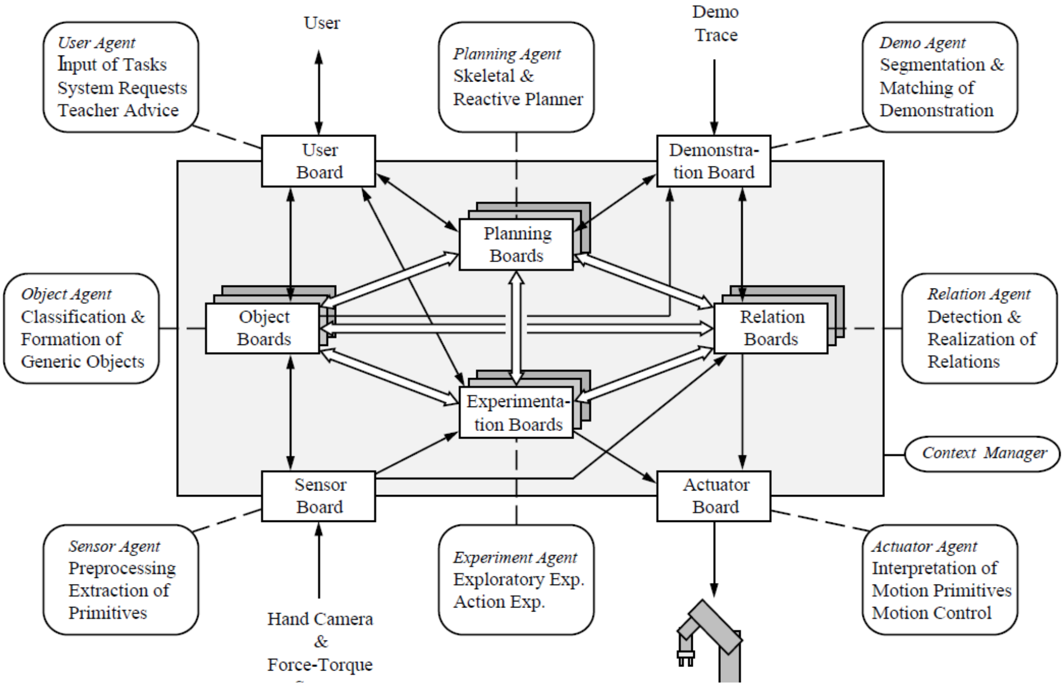

Fig.1 System Architecture

The context consists of the set of active boards and their interconnections. During the solution of a task new boards and channels are dynamically created and related agents take over new interpretation tasks. This will be the case, if new planning or experimentation tasks are necessary or if new objects have to be considered.

5.2 Tele-robotics and Virtual Reality

A *telerobot* is defined for our purposes as a robot controlled at a distance by a human operator, regardless of the degree of robot autonomy makes a finer distinction, which depends on whether all robot movements are continuously controlled by the operator (manually controlled teleoperator), or whether the robot has partial autonomy (telerobot and supervisory control). By this definition, the human interface to a telerobot is distinct and not part of the telerobot. Haptic interfaces that mechanically link a human to a telerobot nevertheless share similar issues in mechanical design and control, and the technology survey presented here includes haptic interface development.

INTRODUCTION

Telerobotic devices are typically developed for situations or environments that are too dangerous, uncomfortable, limiting, repetitive, or costly for humans to perform. Some applications are listed below:

Underwater: inspection, maintenance, construction, mining, exploration, search and recovery, science, surveying.

Space: assembly, maintenance, exploration, manufacturing, science.

Resource industry: forestry, farming, mining, power line maintenance.

Process control plants: nuclear, chemical, etc., involving operation, maintenance, decommissioning, emergency.

Military: operations in the air, undersea, and on land.

Medical: patient transport, disability aids, surgery, monitoring, remote treatment.

Construction: earth moving, building construction, building and structure inspection, cleaning and maintenance.

Civil security: protection and security, firefighting, police work, bomb disposal.

Categorizing past developments in telerobotics:

Remote manipulators

Remote vehicles

Low-level control

Supervisory control

Real-time computing

Relation to Robotics

Telerobots may be remotely controlled manipulators or vehicles. The distinction between robots and telerobots is fuzzy and a matter of degree. Although the hardware is the same or is similar, robots require less human involvement for instruction and guidance than do telerobots. There is a continuum of human involvement, from direct control of every aspect of motion, to shared or traded control, to nearly complete robot autonomy.

Any robot manipulator can be hooked up to a haptic interface and hence become a telerobot. Similarly, any vehicle can be turned into a teleoperated mobile robot. There are many examples in the literature of different industrial robots that have been used as telerobots, even though that was not the original intended use. For example, a common laboratory robot, the PUMA 560, has frequently been teleoperated. There have also been a number of telerobots specifically designed as such, often with a preferred haptic interface. The design issues for robots, telerobots, and haptic interfaces are essentially the same .Often telerobots have to be designed for hazardous environments, which require special characteristics in the design. Industrial robots have most often been designed for benign indoor environments.

Why don't we do everything with robots, rather than involve humans in telerobotic control? We can't, because robots are not that capable. Often there is no substitute for human cognitive capabilities for planning and human sensorimotor capabilities for control, especially for unstructured environments. In telerobotics, these human capabilities are imposed on the robot device. The field of robotics is not that old (35 years), and the task of duplicating (let alone improving upon) human abilities has proven to be an extremely difficult endeavor; it would be disturbing if it were not so. There is a tendency to overextrapolate from the few superior robot abilities, such as precise positioning and repetitive operation. Yet robots fare poorly when adaptation and intelligence are required. They do not match the human sensory abilities of vision, audition, and touch, human motor abilities in manipulation and locomotion, or even the human physical body in terms of compact and powerful musculature that adapts and self-repairs, and especially in terms of a compact and portable energy source. Hence in recent years many robotics researchers have turned to telerobotics, partly out of frustration.

Nevertheless, the long-term goal of robotics is to produce highly autonomous systems that overcome hard problems in design, control, and planning. As advances are made in robotics, they will feed through to better and more independent telerobots. For example, much of the recent work in low-level teleoperator control is influenced by developments in robot control. Often, the control ideas developed for autonomous robots have been used as the starting points for slave, and to a lesser extent, master controllers. Advances in high-level robot control will help in raising the level of supervisory control.

Yet the flow of advances can go both ways. By observing what is required for successful human control of a telerobot, we may infer some of what is needed for autonomous control. There are also unique problems in telerobotic control, having to do with the combination of master, slave, and human operator. Even if each individual component is stable in isolation, when hooked together they may be unstable. Furthermore, the human represents a complex mechanical and dynamic system that must be considered.

5.2.1 Relation to Virtual Environments

Telerobotics encompasses a highly diversified set of fundamental issues and supporting technologies . More generally, telerobots are representative of human-machine systems that must have sufficient sensory and reactive capability to successfully translate and interact within their environment. The fundamental design issues encountered in the field of telerobotics, therefore, have significant overlap with those that are and will be encountered in the development of veridical virtual environments (VEs). Within the virtual environment, the human-machine system must allow translation of viewpoint, interaction with the environment, and interaction with autonomous agents. All this must occur through mediating technologies that provide sensory feedback and control. The human-machine interface aspects of telerobotic systems are, therefore, highly relevant to VE research and development from a device, configuration, and human performance perspective.

Yet the real-environment aspect of telerobotics distinguishes it from virtual environments to some extent. Telerobots must:

- interact in complex, unstructured, physics-constrained environments,
- deal with incomplete, distorted, and noisy sensor data, including limited views, and
- Expend energy which may limit action.

The corresponding features of virtual environments are more benign:

Form, complexity, and physics of environments are completely controllable.

Interactions based on physical models must be computed.

Virtual sensors can have an omniscient view and need not deal with noise and distortions.

The ability to move within an environment and perform tasks is not energy-limited.

Despite such simplifications, virtual environments play an important role in telerobotic supervisory control. A large part of the supervisor's task is planning, and the use of computer-based models has a potentially critical role. The virtual environment is deemed an obvious and effective way to simulate and render hypothetical environments to pose "what would happen if" questions, run the experiment, and observe the consequences. Simulations are also an important component of predictive displays, which represent an important method of handling large time delays. VE research and development promises to revolutionize the field of multimodal, spatially oriented, interactive human-machine interface technology and theory to an extent that has not been achievable in the robotics field. The two fields should therefore not be viewed as disparate but rather as complementary endeavours whose goals include the exploration of remote environments and the creation of adaptable human-created entities.

5.3 Micro & Nanorobots

The field of microrobotics covers the robotic manipulation of objects with dimensions in the millimeter to micron range as well as the design and fabrication of autonomous robotic agents that fall within this size range. Nanorobotics is defined in the same way only for dimensions smaller than a micron. With the ability to position and orient objects with micron- and nanometer-scale dimensions, manipulation at each of these scales is a promising way to enable the assembly of micro- and nanosystems, including micro- and nanorobots.

Progress in robotics over recent years has dramatically extended our ability to explore, perceive, understand, and manipulate the world on a variety of scales extending from the edges of the solar system, to the bottom of the sea, down to individual atoms. At the lower end of this scale, technology has been moving toward greater control of the structure of matter, suggesting the feasibility of achieving thorough control of the molecular structure of matter atom by atom, as Richard Feynman first proposed in 1959 in his prophetic article on miniaturization.

Feynman foresaw the possibility of employing a microrobotic manipulator (*a master–slave system*) for bottom-up manufacturing (manipulation, assembly, etc.) of minute machines; one such device he described as "swallowing the surgeon". Micro- and nanorobotics research has progressed from these seemingly *far-out* concepts of the 1960s and 1970s to reality when microelectromechanical systems (MEMS) began to emerge in the late 1980s. These building blocks took the form of surface-micro machined micro motors and micro grippers made of polysilicon fabricated on a silicon chip..Today, a variety of microrobotic devices are enabling new applications in various fields.

In industry, interesting areas for microrobotics include assembly characterization, inspection and maintenance microoptics (positioning of microoptical chips, microlenses and prisms) and microfactories Many of these applications require automated handling and assembly of small parts with accuracy in the submicron range.

Other important fields include biology (manipulation, capturing, sorting and combining cells and medical technology. In surgery, the use of steerable catheters and endoscopes is very attractive and the development of increasingly small microrobotic devices is rapidly progressing. Wireless

untethered microrobots that will explore and repair our bodies (“swallowing the surgeon”) appear to be simply a matter of time. In fact, endoscopy using wireless capsules (camera pills) is already on the market and allow for endoscopic imaging of the entire gastrointestinal tract. something currently not possible using standard scopes. Magnetic steering or crawling type motions serve as promising ways for such devices to
locomote in a controlled fashion. Doctors could steer pill-mounted cameras and other actuators to areas of interest for visual investigation and biopsies beyond the range of current endoscopes.

Nanorobotics represents the next stage in miniaturization for maneuvering nanoscale objects.
Nanorobotics is the study of robotics at the nanometer scale, and includes robots that are nanoscale in size, i. e., nanorobots, and large robots capable of manipulating objects that have nanometer dimensions with nanometer resolution, i. e., nanorobotic manipulators.
The field of nanorobotics brings together several disciplines, including nanofabrication processes used for producing nanoscale robots, nanoactuators, nanosensors, and physical modeling at nanoscales. Nanorobotic manipulation technologies, including the assembly of
nanometer-sized parts, the manipulation of biological cells or molecules, and the types of robots used to perform these types of tasks also form a component of nanorobotics.

One of the most important applications of nanorobotic manipulation will be nanorobotic assembly. However, it appears that, until assemblers capable of replication can be built, the combination of chemical synthesis and self-assembly are necessary when starting from atoms; groups of molecules can self-assemble quickly due to their thermal motion, enabling them to *explore* their environments and find (and bind to) complementary molecules.

Classification of Microrobots

- task
- size,
- mobility
- functionality

Many robots usually consist of sensors and actuators, a control unit, and an energy source.

- Depending on the arrangement of these components, one can classify microrobots according to the following criteria:
- locomotive and positioning possibility

- manipulation possibility
- control type (wireless or tethered)
- Autonomy
- The majority of MEMS-based microrobotic devices developed so far could be categorized as moveable links
  - ✓ Microcatheters and microgrippers
  - ✓ Smart pills

5.4 Cognitive robotics

Cognitive robotics is a new approach to robot programming based on high level primitives for perception and action. These primitives draw inspiration from ideas in cognitive science

Endowing robotic or software agents with higher level cognitive functions that involve reasoning, for example, about goals, perception, actions, the mental states of other agents, collaborative task execution, etc.

Cognitive Robotics as building robots with cognitive capabilities:

−High-Level Perception and Action

−Attention

−Memory

−Learning

−Concept Formation

−Reasoning and Problem Solving

−Communication and Use of Language

−Theory of Mind

−Social Interaction

Cognitive Robotics can be used to drive the science of cognition

–Cognitive robotics as a platform to test theories about human cognition.

–Cognitive Science as the science of all forms and kinds of cognition and cognitive agents, whether these be human, animal, alien, robot, or otherwise. Thus:
–Robotic systems are cognitive systems, and are interesting to study in and of themselves

Cognitive Robotics as Experimental Cognitive Science

–Cognitive Robotics as the use of robotics to explore cognitive systems or architectures, to develop new concepts and frameworks of cognition, and to formulate and test cognitive hypothesis.

Traditional Cognitive Architecture

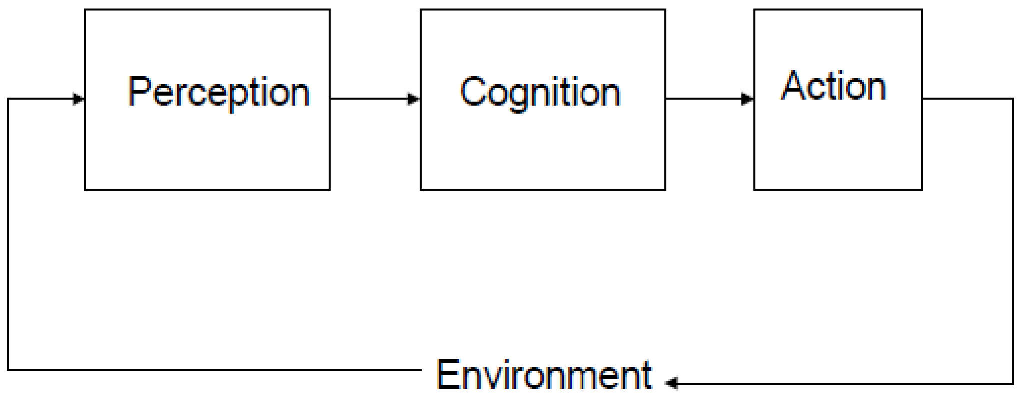

Fig.5.2 Operation of a Cognitive Robot

Cognition is the process by which an autonomous system **perceives** its environment, **learns** from experience, **anticipates** the outcome of events, **acts** to pursue goals, and **adapts** to changing circumstances."

Cognitive robots achieve their goals by

(1)Perceiving their environment

Perception makes use of many sensory modalities, e.g. vision, audition, and haptic (tactile and kinesthetic)

(2) Paying attention to the events that matter

Selective- Selecting a given feature or object

Restrictive- restricting what to look for or where to look for it

Suppressive-suppressing features, objects, or locations that are deemed to be not relevant

(3) Anticipating the need for some action

- Anticipation; also referred to as prospection

- The anticipated action is often associated with achieving a goal
- Four modes of operation:
  Simulation, prediction, intention, and planning

(4) Planning what to do

- Planning is sometimes effected by reasoning about the current state of the world or anticipated futures states
- Exploits memories of past experience (episodic memory) and knowledge of the world (semantic memory)

(5) Anticipating the outcome as it executes the action

Anticipating the outcome of a possible action can refer to the actions of the robot itself or the actions of other agents (people and other robots)

(6)Learning from the resultant interaction

Learning from actions means that future actions can be more effective or more efficient, often based on reasoning.Sometimes referred to as meta-cognition or meta-reasoning (the focus is on improving the cognitive or reasoning process)

(7)Adapting to change

Adaptation is also achieved through Learning.In this case, the result of learning is new action policy rather than improved action policy.

- A key feature of cognitive robotics is the focus on prospection to augment immediate sensory motor experience, both when navigating and manipulating objects in the robot's environment and when interacting with people.
- Cognitive robots are able to carry out tasks effectively by anticipating the effects of their own actions as well as the actions of the people around them.
- Being able to view the world from another person's perspective, a cognitive robot can anticipate that person's intended actions and needs and, consequently, it can interact safely while performing tasks in everyday situations.
- This applies both during direct interaction (e.g. a robot assisting a customer in a supermarket) and indirect interaction (e.g. a robot stacking shelves while customers are shopping).

5.5 EVOLUTIONARY ROBOTS

Evolutionary robotics is a computer-simulated method of creating intelligent, autonomous robots with particular traits, based on the principles of Darwin's theory of evolution. In evolutionary robotics, autonomous robots are treated as organisms that can function and evolve independently of humans.

Evolutionary robotics is related to developmental robotics, but takes a different approach. Evolutionary robotics involves populations of robots. Developmental robotics is concerned with the increase in individual robots' intelligence as they acquire experience in their environments.

The goal of the approach is to enable robots to operate in a self-contained manner without relying on external entities for assessment of performance or additional computing power. To that end, the main components of the EA (evaluation, selection, and reproduction) are carried out autonomously by the robots without any external supervision. The main advantage of online evolution is that if the environmental conditions or task requirements change, the robots can modify their behavior to cope with the new circumstances.

Evolutionary Robotics is a field of Autonomous Robotics where the controllers that implement behaviours are obtained through some kind of Evolutionary Algorithm. The aim behind this technique is to obtain controllers minimizing human intervention. This is very interesting in order to achieve complex behaviours without introducing a “human bias”. Sensors, body and actuators are usually different for a human being and for a robot, so it is reasonable to think that the best strategy obtained by the human designer is not necessarilythe best one for the robot. This article will briefly describe Evolutionary Robotics and its advantages over other approaches to Autonomous Robotics as well as its problems and drawbacks.

Algorithms:

The basis of Evolutionary Robotics is to use evolutionary algorithms to automatically obtain robot controllers. In order to do that, there are many decisions to be made. First of all, one must decide what to evolve (controllers, morphology, both?). Then, whatever is to be evolved has to be encoded in chromosomes. An evolutionary algorithm must be chosen. It has to be decided where and how to evaluate each individual, etc. These issues will be addressed in the following sections.

Evolutionary Algorithm: Stochastic population based search algorithm inspired on natural evolution. The problem is encoded in an n-dimensional search space where individuals represent candidate solutions. Better individuals have higher reproduction probabilities than worse individuals, thus allowing the fitness of the population to increase through the generations

Macro Evolutionary Algorithm: Evolutionary algorithm using the concept of species instead of individuals. Thus, low fitness species become extinct and new species appear to fill their place. Its evolution is smoother, slower but less inclined to fall into local optima as compared to other evolutionary algorithms

Autonomous Robotics: The field of Robotics that tries to obtain controllers for robots so that they are tolerant and may adapt to changes in the environment.

Knowledge Based Robotics: The field of Autonomous Robotics that tries to achieve "intelligent" behaviours through the modelling of the environment and a process of planning over that model, that is, modelling the knowledge that generates the behaviour

Behaviour Based Robotics: The field of Autonomous Robotics that proposes not to pay attention to the knowledge that leads to behaviours, but just to implement them somehow. It also proposes a direct connection between effectors and actuators for every controller running in the robot, eliminating the typical sensor interpretation, world modelling and planning stages

Evolutionary Robotics: The field of Autonomous Robotics, usually also considered as a field of Behaviour Based Robotics, that obtains the controllers using some kind of evolutionary algorithm

Artificial Neural Network: An interconnected group of artificial neurons, which are elements that use a mathematical model that reproduce, through a great simplification, the behaviour of a real neuron, used for distributed information processing. They are inspired by nature in order to achieve some characteristics presented in the real neural networks, such as error and noise tolerance, generalization capabilities, etc.

The issues arised in ER are:

(1) the reality gap which occurs when controllers evolved in simulation become ineffectiveonce transferred to the physical robot,

(2) the prohibitively long time necessary to evolve controllers directly on real robots

A number of approaches have been introduced to cross the reality gap. There are three complementary approaches:

(1) using samples from the real robots' sensors,

(2) introducing a conservative form of noise in simulated sensors and actuators, and

(3) Continuing evolution for a few generations in real hardware if a decrease in performanceis observed when controllers are transferred.

Using samples from real sensors increases the accuracy of simulations by using a more realistic sensor model, which in turn can decrease the difference between the sensory input experienced in simulation and in reality.

Noise can be applied to promote the evolution of robust controllers that can better tolerate variations in the sensory inputs during task execution. Finally, if the performance of the controller decreases after transfer, continuing evolution on real hardware can potentially enable the synthesis of a well-adapted controller in a timely manner.

Table 1: Summary of approaches introduced to cross the reality gap.

Approach	Tasks	Robot Type
Sensor sampling	Navigation and obstacle avoidance	Wheeled
Conservative noise	Navigation and obstacle avoidance	Wheeled
Evolution and learning	Navigation and obstacle avoidance, sequential light-switching	Wheeled
Minimal simulations	T-maze navigation, shape recognition, locomotion, and obstacle avoidance	Wheeled, gantry, 8-legged
Transferability approach	T-maze navigation, locomotion	Wheeled, 4-legged

(4) bootstrap problem when solutions to complex tasks are sought.

(5) deception

(6) the design of genomic encodings and of the genotype-phenotype mappings that enable the evolution of complex behaviours and

(7) the absence of standard research practices in the field

Importantly, while issues such as the bootstrap problem and deception are inherent to the evolutionary computation approach, other issues such as the reality gap and the time-consuming nature of evolving controllers on real robots are specific to ER. In addition, the differences between ER and more traditional domains mean that there is currently a lack of theory and formal methods that can be applied to ER.

5.6 Humanoid robots

Humanoid robots have been assisting humankind in various capacities. They have been broadly used in the field of Healthcare, Education, and Entertainment. A humanoid robot is a robot that not only resembles the human's physical attributes, especially one head, a torso, and two arms, but also can communicate with humans, take orders from its user, and perform limited activities. Most humanoid robots are equipped with sensors, actuators, cameras, and speakers. These robots are typically preprogrammed for specific actions or have the flexibility to be programmed according to the user requirement.

Generally, humanoid robots are designed according to their intended application.

Based on applications, humanoid robots can be broadly categorized into Healthcare, Educational and Social humanoid robot.

Healthcare humanoid robots are designed and used by individuals at home or healthcare centres to treat and improve their medical conditions. These robots either require a human controller or are preprogrammed to assist patients.

Educational humanoid robots are primarily designed and equipped for students and are used in education centres or home to improve education quality and increase involvement in studies. These robots are typically but not always manually controlled robots.

Social humanoid robots are used by individuals or organizations to help and assist people in their daily life activities. These robots are commonly preprogrammed to perform mundane tasks and are also known as assistive robots.

History and Overview

There is a long history of mechanical systems with human form that perform human-like movements. For example, Al-Jazari designed a humanoid automaton in the 13th century , Leonardo da Vinci designed a humanoid automaton in the late 15th century and in Japan there is a tradition of creating mechanical dolls called Karakuri ningyo that dates back to at least the 18th century In the 20th century, animatronics became an attraction at theme parks. For example, in 1967 Disneyland opened its Pirate's of the Caribbean ride which featured animatronic pirates that play back human-like movements synchronized with audio. Although programmable, these humanoid animatronic systems moved in a fixed open-loop fashion without sensing their environment.

In the second half of the 20th century, advances in digital computing enabled researchers to incorporate significant computation into their robots for sensing, control, and actuation. Many roboticists developed isolated systems for sensing, locomotion, and manipulation that were inspired by human capabilities. However, the first humanoid robot to integrate all of these functions and capture widespread attention wasWABOT-1, developed by Ichiro Kato et al. at Waseda University in Japan in 1973 .

The WABOT robots integrated functions that have been under constant elaboration since: visual object recognition, speech generation, speech recognition, bimanual object manipulation, and bipedal walking.

WABOT-2's ability to play a piano, publicized at the Tsukuba Science Expo in 1985, stimulated significant public interest. In 1986,Honda began a confidential project to create humanoid biped.

In parallel with these developments, the decade long *Cog project* began in 1993 at the MIT Artificial Intelligence laboratory in the USA with the intention

of creating a humanoid robot that would, *learn to 'think' by building on its bodily experiences to accomplish progressively more abstract tasks.* This project gave rise to an upper-body humanoid robot whose design was heavily inspired by the biological and cognitive sciences. Since the inception of the Cog project, many humanoid robotics projects with similar objectives have been initiated, and communities focused on developmental robotics, autonomous mental development (AMD) and epigenetic robotics have emerged .

As of the early 21st century, many companies and academic researchers have become involved with humanoid robots, and there are numerous humanoid robots across the world with distinctive features.

Different Forms

Today, humanoid robots come in a variety of shapes and sizes that emulate different aspects of human form and behaviour. As discussed, the motivations that have driven the development of humanoid robots vary widely. These diverse motivations have lead to a variety of humanoid robots that selectively emphasize some human characteristics, while deviating from others. One of the most noticeable axes of variation in humanoid robots is the presence or absence of body parts. Some humanoid robots have focused solely on the head and face, others have a head with two arms mounted to a stationary torso, or a torso with wheels), and still others have an articulate and expressive face with arms, legs, and a torso. Clearly, this variation in form impacts the ways in which the robot can be used, especially in terms of mobility, manipulation, whole-body activities, and human–robot interaction.

Different Degrees of Freedom

Humanoid robots also tend to emulate some degrees of freedom in the human body, while ignoring others. Humanoid robots focusing on facial expressivity often incorporate actuated degrees of freedom in the face to generate facial expressions akin to those that humans can generate with their facial muscles. Likewise, the upper body of humanoid robots usually includes two arms, each with a one-degree-of-freedom (one-DOF) rotary joint at the elbow and a three-DOF rotary joint for the shoulder, but rarely attempt to emulate the human shoulder's ability to translate or the flexibility of the human spine .

In general, humanoid robots tend to have a large number of degrees of freedom and a kinematic structure that may not be amenable to closed-form analysis due to redundancy and the lack of a closed-form inverse. This is in contrast to traditional industrial manipulators that are often engineered to have minimal redundancy (six DOFs) and more easily analyzed kinematic structures.

Different Sensors

Humanoid robots have made use of a variety of sensors including cameras, laser range finders, microphone arrays, lavalier microphones, and pressure sensors.
Some researchers choose to emulate human sensing by selecting sensors with clear human analogs and mounting these sensors on the humanoid robot in a manner that mimics the placement of human sensory organs. Two to four cameras are often mounted within the head of a humanoid robot with a configuration similar to human eyes.

The justifications for this bias towards human-like sensing include the impact of sensing on natural human–robot interaction, the proven ability of the human senses to support human behaviour, and aesthetics. For example, with respect to human–robot interaction, nonexperts can sometimes interpret the functioning and implications of a human-like sensor, such as a camera, more easily. Similarly, if a robot senses infrared or ultraviolet radiation, the robot will see a different world than the human. With respect to behaviour, placement of sensors on the head of the robot allows the robot to sense the world from a van tage point that is similar to that of a human, which can be important for finding objects that are sitting on a desk or table.

Prominent humanoid robots have added additional sensors without human analogs. For example, Kismet used a camera mounted in its forehead to augment the two cameras in its servoed eyes, which simplified common tasks such as tracking faces. Similarly, versions of Asimo have used a camera mounted on its lower torso that looks down at the floor in order to simplify obstacle detection and navigation during locomotion.

Other Dimensions of Variation

Other significant forms of variation include the size of the robot, the method of actuation, the extent to which the robot attempts to appear like a human, and the activities the robot performs.