The role of artificial intelligence in robotics

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Abstract

Purpose – This paper aims to provide an insight into the use of artificial intelligence (AI) in robotics.

Design/methodology/approach – Following an introduction to AI, this paper provides an overview of the application of AI to robotics. Mobile robots are then discussed, together with the various AI techniques employed and under development. The application of the OpenCog artificial general intelligence architecture is then considered and the paper concludes with a brief discussion.

Findings – This shows that many AI concepts are being applied to humanoid, mobile and other classes of robots. Significant progress has been made and many innovative AI strategies are being studied which often seek to emulate aspects of human intelligence. Much development activity is being driven by military interests but as yet, the level of intelligence exhibited by the most advanced robots is at best equivalent to that of a very young child. Several academics argue that more rapid progress will arise from a closer integration of AI and robotic research.

Originality/value – This article discusses the role of AI in robotics and provides details of number of robotic developments involving a range of AI concepts.

Keywords Cognition, Autonomy, Artificial intelligence, Robotics

Paper type Technical paper

Introduction to artificial intelligence

The term "artificial intelligence" (AI) was coined by the late John McCarthy of Stanford University in 1956 and his paper "Programs with common sense", published in 1958, is regarded by many as the first on logical AI. The AI field was founded on the premise that a central property of humans, intelligence, can be so precisely described that it can be simulated by a machine. McCarthy defined AI as "the science and engineering of making intelligent machines" and today many researchers think of AI as "the study and design of intelligent agents", where an intelligent agent is a system that perceives its environment and takes actions that maximise its chances of success in a particular task. Some key attributes of an "intelligent" machine include inference, reasoning, learning from experience, planning, pattern recognition and epistemology.

The archetypal means of determining whether a device exhibits AI is the Turing test. Proposed by Alan Turing in 1950, before the term AI had been coined, this is a test of a machine's ability to exhibit intelligent behaviour equivalent to, or indistinguishable from, that of a human. In its original form, a human judge engages in natural language conversations with a human and a machine designed to generate performance indistinguishable from that of a human. If the judge cannot reliably tell the machine from the human, the machine is said to have passed the test. The test does not check the ability to give the correct answer to questions but checks how closely they resembles typical human answers. The validity of this and subsequent tests has been the topic of much debate but Turing predicted that machines would eventually be able to pass the test and estimated that by the year 2000, machines with 10 GB of storage would be able to fool 30 per cent of human judges in a 5-minute test. By extrapolating an exponential growth in technology over several decades, Ray Kurzweil, Futurist and a Director of Engineering at Google, predicted that Turing test-capable computers would certainly be developed and in 1990, he set the year at around 2020 but by 2005, he had revised this to 2029. Nevertheless, progress has been made; for instance, in 1997, IBM's Deep Blue (Figure 1) became the first chess-playing computer to beat a reigning world champion, Garry Kasparov.

AI has been the subject of tremendous optimism as well as having suffered several major setbacks such as the failure to achieve machine translation in the mid-1960s and the failure of Japan's ¥50 billion "Fifth Generation" computer systems project in the 1980s. Funding for and interest in the technology has waxed and waned over the last five decades but today it is again in its ascendancy, in part due to the commercial success of expert systems, a form of AI programme that simulates and exploits the knowledge and analytical skills of human experts in such diverse fields as medical diagnosis and stock market trading.

AI and robotics

Many industry commentators argue that the application of AI is the most significant and certainly one of the most exciting field of robotic development. While intelligent computers may one day be able to "think" like a human, an intelligent robot could act and conduct all manner tasks in a human-like manner. AI technologies have the potential to play a role in a diversity of robots, including companion and caring robots including humanoid types, autonomous land, air and sea vehicles, swarm robots, search and rescue robots, service and assembly robots, robotic toys, a variety of military robots and intelligent prostheses. Many aspects of AI have a role to play, include speech recognition, dexterous manipulation, autonomous navigation, machine vision, pattern recognition and localisation and mapping, together with capabilities that are at

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Figure 1 Deep Blue, now in the Smithsonian Museum, was hailed as a milestone in AI research, being the first computer to beat a reigning world chess champion

Source: Wikipedia

the very heart of advanced AI such as learning from experience and predicting the outcome of actions. Numerous groups from around the world are working on robotic developments involving these technologies.

However, AI is a very fragmented field: well developed and largely independent research communities exist for fields such as learning and reasoning, language, perception, control and other technologies. Since the challenges posed by each of these are immense, most AI researchers devote their efforts to specialising in a single field but while great progress has been made in each of these in the last few decades, how they can be integrated to produce an intelligent robot remains unclear. Because of this specialisation and fragmentation and the many different classes of robots to which AI could be applied, intelligent robotics research tends to be equally fragmented, with many groups focusing on a particular theme or capability. Much is not referred to as AI, as many of the technologies involved, such as machine vision, pattern recognition and learning algorithms are now routinely used in many fields of robotics. Accordingly, some academics argue that unifying these disparate AI technologies is critical if truly intelligent robots are to be developed and that integration should be considered as a valid research endeavour in its own right. Indeed, reflecting this view, a symposium "Designing Intelligent Robots: Reintegrating AI" was organised by the Association for the Advancement of Artificial Intelligence and held at Stanford University in 2012. This brought together a diverse and multidisciplinary group of researchers interested in the specific goal of designing intelligent robots and was followed by a second symposium on a similar theme in 2013.

Mobile robots

Two fields of robotics that arguably embody the greatest number of AI concepts are humanoid robots and autonomous, mobile robots. Perhaps, the best known humanoid robot is Honda's Asimo (Figure 2) which has the ability to recognise moving objects, postures, gestures, its environment, sounds and faces, which allows it to interact in a limited manner with humans. While originally designed to be a multi-functional mobile robotic assistant with the ability to help those who lack full mobility, it is now more of a technology demonstrator. Conversely, autonomous or semi-autonomous mobile robots and robotic vehicles are being developed to conduct very specific tasks such as search and rescue operations and a range of military applications. These are attracting world-wide interest and many have been developed over the years. In addition to several driverless car projects conducted by major vehicle manufacturers, much recent progress has been driven by American military interests through the Defence Advanced Research Projects Agency (DARPA). In 2005, a robotic vehicle "Stanley" (Figure 3), developed at Stanford University won the DARPA Grand Challenge by driving autonomously for 131 miles along an unrehearsed desert trail. It utilises raw data from LIDAR, the camera, GPS and inertial sensors which are fed into software programmes to control the vehicle's speed, direction and decision making functions. It employed a machine learning-based approach to obstacle detection and LIDAR data were fused with images from the vision system to perform more distant look-ahead. If a path of drivable terrain could not be detected for at least 40 m in front of the vehicle, the speed was decreased and the LIDAR was used to locate a safe passage.

Figure 2 Honda's Asimo robot

Source: Wikipedia

Figure 3 The Stanley robotic vehicle

Source: Wikipedia

Two years later, a team from Carnegie Mellon University with support from General Motors won the DARPA Urban Challenge when their vehicle "Boss" autonomously navigated 55 miles in an urban environment while adhering to traffic hazards and complying with all traffic laws. General Motors and Nissan have recently announced that they will introduce completely autonomous cars by the end of the decade. Mobileye, a manufacturer of camera technology for automotive safety, founded by Professor Amnon Shashua, an Israeli Computer Scientist, has made considerable progress in this field. While most academic groups and automotive manufacturers have used a multitude of sensors including radar, cameras, inertial sensors and LIDAR/lasers (Figure 4) and fusing the data to provide a detailed map of the rapidly changing environment around a moving car, Mobileye is attempting to achieve a similar level of performance with just video cameras and specialised AI software.

Figure 4 A vehicle entered in the DARPA Urban Challenge showing the multitude of sensors used to achieve autonomous operation

Source: Wikipedia

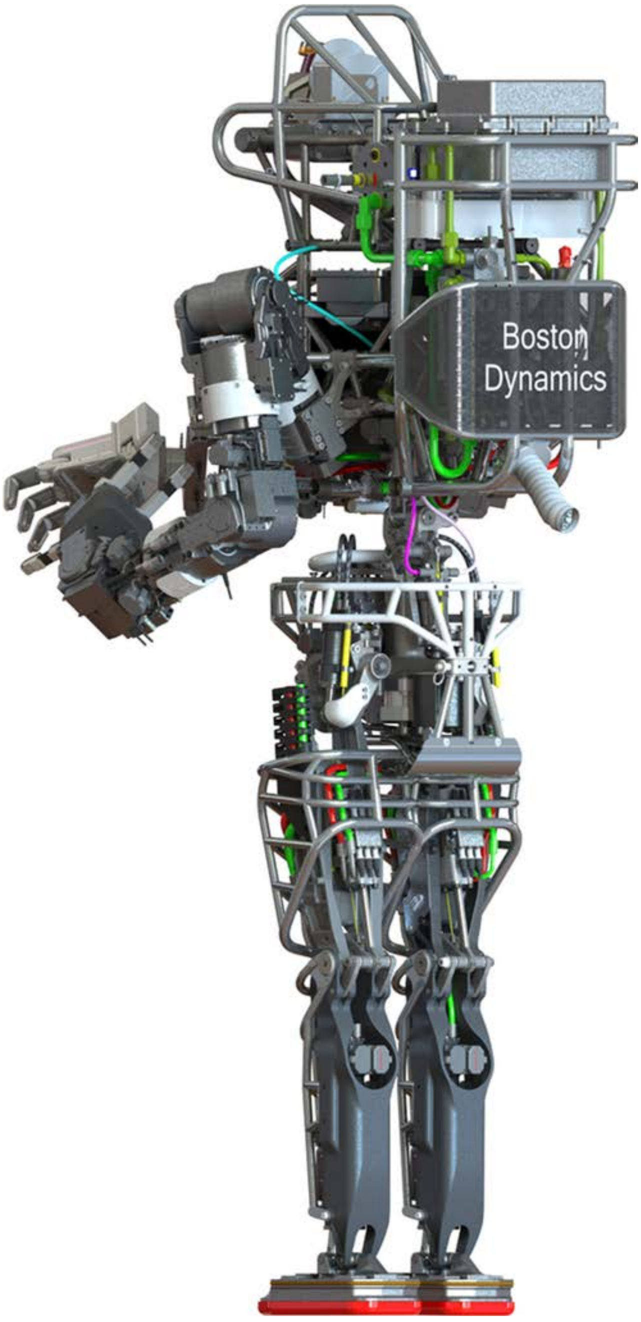
Most recently, the DARPA Robotics Challenge (DRC) was held at Florida's Homestead Miami Speedway in December 2013. Sixteen teams competed in a series of trials which involved eight tasks to assess their potential for use in disaster response and also to provide a baseline on the current state of mobile robot technology. The tasks tested the robots' mobility, manipulation ability (Figure 5), dexterity, perception and operator control mechanisms. In contrast to earlier DARPA challenges involving vehicles, the majority of the robots competing in the DRC were bipedal designs (Figure 6) and the winning team which scored 27 points out of a possible 32 was from Schaft Inc., a spin-off from the University of Tokyo that has created a biped robot (Figure 7) in which the standard servo motors and batteries are replaced by high output, capacitor-powered, water-cooled motors. Schaft was acquired by Google earlier this year, along with several other robotics companies. Google was dominant in the competition, fielding several other teams, including second placed IHMC Robotics, which used an Atlas robot manufactured by Boston Dynamics, which was recently acquired by the search company. The robots use state of the art computing, algorithms, machine vision and other AI technologies yet the level of "intelligence" and competence exhibited by the time of the finals in 2014 is expected to be roughly that of two year-old child, giving them the ability to carry out autonomously simple commands such as "Clear the debris in front of you" or "Close the valve". This is clearly significant but illustrates only too well the limitations of today's technology.

A further example of intelligent robotic developments being driven by military interests is the research being conducted at the US Army Research Laboratory, Human Research and Engineering Directorate (HRED). The aim is to develop mobile robots that can navigate autonomously in their environment when given a human voice command and operate under a variety of battlefield conditions. The AI technique involved is the Symbolic and Sub-Symbolic Robotics Intelligence Control System (SS-RICS), which was developed by HRED in cooperation with Towson State University in 2004 and which combines symbolic and sub-symbolic representations of knowledge into a unified control structure. This is a goal-oriented production system (a programme typically used to provide a form of AI which consists of a set of rules about behaviour), based loosely on

Figure 5 A mobile robot conducting a complex manipulation task during the DRC

Source: DARPA

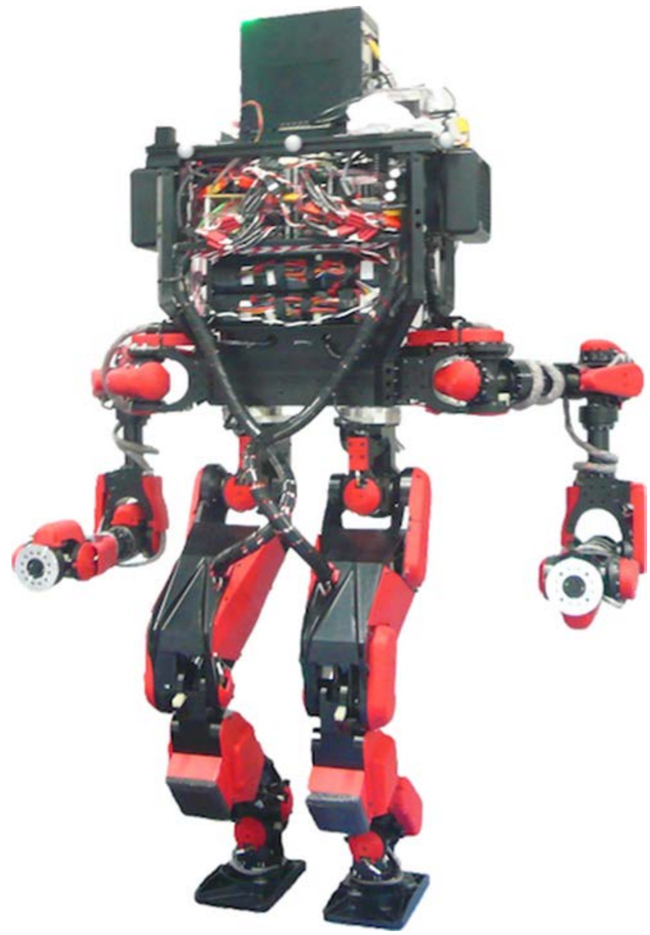
Figure 6 The Atlas robot manufactured by Boston Dynamics



Source: DARPA

the cognitive architectures, the Adaptive Character of Thought-Rational (ACT-R) and Soar, which was developed at the University of Michigan. In development for 30 years, Soar is a general cognitive architecture that integrates knowledge-intensive reasoning, reactive execution, hierarchical reasoning, planning and learning from experience, with the goal of creating a general computational system that has the same cognitive abilities as humans. HRED researchers found that in order to simulate complex cognition in a robot, several aspects such as long-term memory and perception needed to be in place before any generalised intelligent behaviour can be produced. Cognition arises from a collection of different algorithms, each with

Figure 7 The Schaft bipedal robot



Source: DARPA

different functionalities, which together produce the integrated process of cognition. This is also known as a functionalist representation. HRED is developing SS-RICS to be a modular system, or as a collection of modular algorithms, each with different responsibilities for the functioning of the overall system. The important component is the interaction or interplay amongst these different algorithms, which leads to an integrated cognitive system. According to Troy Kelley, Cognitive Robotics Team Leader at HRED:

> We are not necessarily attempting to produce a neurological representation of the individual components of the brain. The basic idea is that we are trying to use psychological theory to augment robotics development, especially in areas of learning and memory.

HRED has been concentrating on implementations of human memory as a way of reducing the computational load faced by autonomous systems. For example, it is understood from psychology experiments that humans load elements from long-term memory into working memory when they are given a problem solving task. Once long-term memories are accessed, humans are then able to concentrate on a specific task. This separation of long-term memories from working memory allows for increased computation efficiency because only the knowledge related to a specific task are searched for during problem solving. This implementation can be replicated on an autonomous system to help reduce the computational load.

Other human memory implementations would include memory decay (i.e. forgetting unimportant information) and associative learning (i.e. things that happen together get remembered together).

One of the techniques proposed to reduce the computational load in a mobile robot is to provide environmental intelligence through the use of dispersed wireless sensors. While not suitable for applications in unstructured environments such as a battlefield, the sensors can act as active landmarks for vehicle localisation and navigation in more controlled situations. A mosaic of wireless cameras distributes the massive on-board intelligence required for autonomous robots to the external environment. However, wireless sensors are often resource-scarce and require a resource-saving design. In work at the University of Hull, a multiple Bloom-filter scheme is used, together with an active contour-based scheme for path planning, trajectory generation and motion control. The Bloom filter is used to compress a global routing table for a wireless sensor and serves as a lookup table for routing a robotic vehicle to any destination but requires significantly reduced memory space and search effort. The concept has been demonstrated in a prototype intelligent environment consisting of 30 wireless sensors (cameras) for the indoor navigation of an environment-controlled wheelchair. This work shows that a robot with reduced intelligence can still exhibit sophisticated mobility.

Cognitive synergy: an alternative approach to AI

An intriguing and ambitious project which seeks to advance the science and engineering of "super intelligent" robotics is being conducted by Geni Lab, a non-profit-making working group. Reflecting the view stated above, that there is a need for a more integrated approach to AI and robotics, the Geni Lab takes a fundamentally different, cross-disciplinary approach by bringing together leading robot scientists and innovators from different disciplines, rather than focusing on isolated aspects of the problem. Specifically, the aim is to impart the Adam Z1 robot, produced by Hanson Robotics, with the mental ability of a three-year-old child. By using the OpenCog artificial general intelligence (AGI) architecture the objective is to create the first AI system with real "common sense understanding". It is hoped that this will be the first robot to be fully integrated with OpenCog, one of the few active software platforms in the world that strives to achieve human-like intelligence, rather than more specific AI applications such as self-driving cars. OpenCog is a diverse assemblage of cognitive algorithms, each embodying their own innovations, but what makes the overall architecture powerful is its adherence to the principle of "cognitive synergy". It aims to capture the spirit of the brain's architecture and dynamics without imitating the details, most of which are largely unknown, by integrating together a combination of cognitive algorithms acting on different kinds of knowledge in a scalable and flexible C++ software architecture. These are designed to co-operate with cognitive synergy for tasks characteristic of human intelligence and to yield a functioning knowledge network in the AI system's "mind" as it interacts with the world, including a self-updating hierarchical/heterarchical ontology. Ultimately, it is hoped that the Adam robot will be able to play with toys, draw pictures with an IPad, communicate with humans, display human emotions at a level that far surpasses current robots, make reasonable and rational decisions and plan accordingly. Clearly, these capabilities would constitute a step-change in robot intelligence. In 2013, the Hong Kong Innovation in Technology Fund (ITF) commenced funding of a two-year project aimed at using OpenCog AGI technology to control the Hanson Robotics "Robokind" humanoid robots. The project takes the form of an industry-university-government collaboration in which the ITF contributes 90 per cent of the cost, Novamente LLC contributes 10 per cent and Hanson contributes two robots. The work will be conducted at Hong Kong Polytechnic University and represents an opportunity to move cognitive robotics and AGI research forward.

Discussion

Robotics and AI have traditionally developed independently and in isolation but the availability of ever-growing processing power has led to the emergence of practical implementations of several AI concepts such as machine vision and learning algorithms which have been adopted widely by the robotics community. There are now growing efforts to unify more closely these fields of research with the aim of dramatically enhancing robot intelligence. However, despite all manner of innovative approaches, today's state of the art still falls very far short of anything approaching adult human intelligence, as evidenced by research whose short-term target is to emulate the cognitive capabilities of a two- or three-year-old child. While some argue that it is only a matter of processing power, others believe that true AI will only emerge following a deep and thorough understanding of how human intelligence works. Whether robots will ever be developed with truly human-like intellectual capabilities remain unclear but with prediction by the AI community that Turing test-capable computers are still several decades away, this must be seen at best as a longer term possibility.

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