AUTONOMY AND LEARNING IN MOBILE ROBOTS

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Abstract

Recent trends in autonomous mobile robots are presented, with an emphasis on machines capable of some degree of learning and adaptation. Following a historical review, the paper discusses developments in humanoids, entertainment robots, service robots, and group robotics. Some of the applications are illustrated with examples from the author's laboratory.

Introduction

A robot as a machine that senses, thinks and acts. Such systems are frequently called *intelligent agents*, or simply *agents*. In this sense, autonomous robots, i.e., robots capable of some degree of independent, self-sufficient behavior, are intelligent agents *par excellence*. They are distinguished from software agents in that robots are embodied agents, situated in the real world. As such, they are subject to both the joys and sorrows of the world. They can be touched and seen and heard (sometimes even smelled!), they have physical dimensions, and they can exert forces on other objects. These objects can be like a ball in robot soccer games, they can be parts to be assembled, airplanes to be washed carpets to be vacuumed, terrain to be traversed or cameras to be aimed. More relevant to this conference, these objects can be tools for assisting persons with disabilities.

Since robots are agents in the world they are also subject to its physical laws, they have mass and inertia, their moving parts encounter friction and hence heat, no two parts are precisely alike, measurements are corrupted by noise, and, alas, parts break. Of course, robots also contain computers, and hence they are also subject to the slings and arrows of computer misfortunes, both in hardware and software. Finally, the world into which we place these robots keeps changing, it is non-stationary and unstructured, so that we cannot predict its features accurately in advance.

In order to adapt to the world, and learn from experience, autonomous robots require sensors to perceive various aspects of their environment and computers to implement various approaches to machine learning. They are an imitation of life, and we are drawn to watching them as they perform their tasks. It is not only the fact that they move, since many things move in the world (sometimes by gravity or sometimes by motor power), but that they move with apparent intelligence and purpose. For those of us who design and build them, this is precisely our goal.

A short history of robot intelligence

During the 19th century there was a great deal of fascination with automata, machines that moved automatically in imitation of living creatures. A number of animated dogs and human figures were built. Churches and public buildings were equipped with moving figures controlled by complex mechanical clockwork. While these machines were not robots in that they did not have sensors to ascertain the state of the world, one may consider their clocks as primitive computers, which controlled the actuators and produced movement. Robots, in the sense of programmable mechanical systems, arose relatively recently. Robot manipulators were proposed by Devol in the United States in 1954; a company started by Devol and Engelberger produced the first commercial versions of these machines in 1962. Industrial robots rapidly assumed an important role in manufacturing (particularly in the automobile industry, where they are used extensively for painting, welding and assembly). In the following 20 years the manufacture of robots gradually shifted from the US to Europe and Japan. Japan currently has the largest number of manufacturing robots of any country in the world. While the early manipulators were strictly pre-programmed mechanical arms, capable only of specific movements in highly structured environments, in recent years they have been equipped with increasing numbers of sensors (such as vision and force) which have given them some ability to adapt to changes in the environment.

However, manipulators used for manufacturing are not autonomous agents, even if they have some degree of adaptability. Another line of development led to the development of mobile robots, which could interact with the world and perform some cognitive functions. In Japan the pioneer in this line of work was Ichiro Kato from Waseda University. The Waseda biped robot that walked many km and the Wasebot piano playing humanoid were the stars of the show during the Japan Expo World’s Fair of 1985. The piano playing robot was a mechanical marvel. It could read sheet music with a video camera and use these inputs to control its arms and ten fingers as it sat on a piano bench. The Japanese fascination with these machines and robots in general is well known [1]. Numerous other walking machines were built in the US, Japan and Europe, with two or four or six or eight legs. Raibert's Pogo stick was a one-legged robot, which maintained its balance as it hopped in a circle at the end of a boom. It and other remarkable machines are described in his book [2]. The foundation of behavior-based control of mobile robots was provided by Brooks [3], in whose laboratory many autonomous robots were designed and built. Perhaps the largest and most varied collection of mobile autonomous robots was designed and constructed by Hirose and his collaborators, e.g. [4,5].

The degree of "intelligence" with which mobile robots are endowed is highly variable. The Waseda piano playing robot was a simple translator from printed notes to finger movement. One may term this intelligent behavior, in the same sense that it requires intelligence to read out loud, i.e., to translate from the printed word to movement of the vocal folds. However, the Waseda piano player had no ability to learn. About 20 years ago, here at Stanford, the robot Shakey was used for experiments in planning and learning. Shakey would take pictures of its surroundings and then plan a path to the next room that avoided obstacles, move a little, take new pictures, re-plan, etc..

Sojourner, the small NASA robot which moved about on the surface of Mars, displayed limited autonomy, but not much intelligence nor the ability to learn.
We discuss other recent "intelligent" robots in later sections of this paper.

<u>Recent developments in robot hardware and software</u>

In recent years there have been dramatic improvements in the subsystems available to build robots. To sense the world, a robot needs sensors, such as cameras to see, ultrasonic and infrared proximity sensors to avoid hitting obstacles, microphones to hear, touch sensors, pressure sensors, an electronic nose for smelling, and so on. Flying robots may be equipped with GPS, thus facilitating localization. All these sensors and many more are now available. Further, since all sensors are noise and imperfect, the information they transmit to the robot may be inconsistent, and some form of sensor fusion is often required. To think, the needs a computer and appropriate algorithms based on artificial intelligence research. In the past this was difficult because computers were too large and too slow and too expensive. All that has changed, and we can put an enormous amount of computation into a few chips. The improvements in computers have been dramatic, and they have made an enormous difference in our ability to build robots with some intelligence.

Robot learning

Many of the standard approaches to machine learning have been applied to learning in robotics, including reinforcement learning, supervised learning, neural networks, evolutionary algorithms, learning by imitation, and several probabilistic approaches. A number of these methods are discussed in a recent publication [6]. In particular, mobile robots are now able to navigate in surprisingly complex environments and learn their properties so their performance improves on successive trials. In our own laboratory, we use mobile robots to explore and map the basic topological features of hallways in buildings. Others, like Thrun and his colleagues [6] use probabilistic approaches and a grid map of an area to obtain accurate metric maps. We are also attempting to use learning by imitation to develop a control strategy for a robot helicopter. Specifically, we use a method called "learning by showing", in which the robot tries to imitate the control signals produced by a human pilot who flies the vehicle by radio. The learning method produces fuzzy rules for coarse control and neural networks for fine control [7].

Humanoids

Both in Japan and the US there is renewed interest in building machines that resemble humans, both in structure and behavior, that display some degree of autonomy. One of the most remarkable is a walking robot designed and built by the Honda company since 1996, is about the size of large person. It wears a helmet, which contains the vision system. It carries a backpack that contains power supplies, computers and communication equipment. This is truly a remarkable robot, capable of walking without falling, not only on a level surface, but also up and down stairs. It has an excellent balance reflex. It can adapt to changes in load and that pressure on its “chest” will cause it to start walking backwards rather than falling. The applications for this robot are not yet clear; it simply demonstrates that a human-like two-legged robot can be built.

Brooks’ current robot being constructed at MIT, named Cog, is a humanoid torso, with head, eye and arm movements, and some ability to hear, learn and speak [8]. Cog learns from interaction with humans. This represents one of the current trends in autonomous robots, i.e., the incorporation of learning. Thus, the development of autonomous robots has moved from emphasis on movement to emphasis on cognition and learning.

Entertainment robotics

The entertainment industry has used "robots" for many years. However, many "robots" in the movies (e.g., the robot "Short Circuit") are teleoperated devices, controlled by hidden human operators. They are not true autonomous robots. The same can be said of the robots used at Disney parks or at Universal Studios. The latter location features a Tyrannosaurus Rex "robot", which is pre-programmed to move as a boat carrying frightened passengers moves by. By contrast with such devices, Sony Corporation has developed a four-legged "pet robot" which was announced commercially in May of this year [9]. In contrast with industrial manipulators or rehabilitation robots, this device is designed entirely for amusement, with no other practical use. I believe that many entertainment robots will be introduced in the next few years. In the US there is a furry toy named Furby which appeared in 1998. Furby can move his head and eyes, recognize some words and learn how to speak perhaps as many as 50 words. The Sony dog does not speak, but it is capable of a number of amazing behaviors. The robot will chase a ball, push it with its paw and follow it around. Of course, it has vision. It also has touch sensors built into its head; a pat on the head will result in a different behavior, such as lying down, or sitting and waving. One of the remarkable things about these robots is that when they fall, they are capable of getting up and continuing to walk. The behavior control computer is implemented on an insertable card, similar to a PCMCIA card.

In the near future Omron Corporation, also from Japan, is expected to introduce a robot "cat", designed as a companion robot for the elderly. The behaviors included with this robot include recognition of the owner's voice, purring when stroked, and following the owner with its head and eye movements.

Devices like the Sony "dog" or the Omron "cat" are true robots, since they sense, think, and act upon the world. They are frequently programmed on the basis of behaviors and they display some limited learning ability. Also, such robots are designed for close contact with humans. This means that they should be perceived as "friendly" rather than potentially dangerous. I believe that the issue of perceived friendliness in these agents will be increasingly important in the future. The Sony robot "pets" were frequently described by such terms as "charming", "lovable", "cute" or "friendly. This is quite a compliment for an inanimate agent.

Human service and cooperation

In addition to the medical and rehabilitation applications discussed at this conference, I believe that more and more robots will be used to assist people in a variety of tasks. Such jobs may include street cleaning, gasoline pumping, vacuuming large carpets, washing aircraft, or inspecting pipelines from the inside. Prototype robots for such tasks have already been built. Some degree of autonomy will be completely essential for such robots. One of the distinguishing features of human service robotics (as with rehabilitation and personal entertainment robots) is the fact that the machines will be working in close proximity to and in cooperation with humans. This is drastically different from the early days of industrial robotics, where great care was taken to insure that humans and robots were well separated to minimize the risk of injury. Such human-robot interaction will require that the agents relate to humans in novel ways, in order to be able to respond to commands, motivations and goals. The agents may be required not only to understand spoken commands, but also to "read" the tone of voice, facial expressions, and gestures of their human coworkers.

The Robotic Engineering Center at Carnegie Mellon University has been developing an autonomous robot tractor (named Demeter). The machine has already demonstrated the ability to operate in large fields and to perform harvesting operations. Autonomous road building machinery is being tested in such applications as excavation, pipe laying, and paving. Construction robots in Japan are being used to assemble steel beam structures and to spray asbestos for fireproofing. In the area of transportation, projects at CMU and in Germany have demonstrated the ability of autonomous passenger automobiles to travel on highways for long distances at normal traffic speeds.

Cooperative groups of robots

The above examples have featured applications of individual robots to specific tasks. Another major trend is the increasing development of computational models and tools to created behavior-based colonies of agents. Work at by Mataric, Arkin, and Fukuda (see, for example, [10]) are only a few examples of a major and growing trend. Our own laboratory at USC is working on a colony of agents (involving both ground-based and flying vehicles) to perform reconnaissance and other tasks, with a minimum of inter-agent communication and outside supervision. Such tasks typically involve the ability of a colony to reach global goals when each agent has only local information.

Conclusion

This paper has presented an overview of some of the current trends in robotics. The survey is not complete by any means, but is intended to indicate some of the current directions in the field. We see robots in the future incorporating the following features:

1. Many robots will include some form of machine learning, applicable to behavior in the real world.

2. Robots will become available in very small sizes. Very tiny robots will be able to swim through bloodstream and identify possible diseases. Very small robots may be able to assemble electronic circuits and microprocessors.

3. There will be more human robot cooperation. Rather than being afraid of robots, people will learn to treat them as partners in many activities. Among such activities will be robot caretakers for elderly people and persons with disabilities, particularly in countries where families tend to separate and not live together. Human-robot interaction will include the ability of the agents to respond to a large variety of commands and cues from humans.

4. There will be more intelligent robots for entertainment and more humanoid robots, which resemble humans in physical appearance, behavior and some aspects of cognition. Emotional components will be included in entertainment robots.

5. There will be more emphasis on group robotics, involving cooperative actions and cooperative problem solving among many robots.

In summary, we can expect that the robots of the future will become more intelligent, have greater ability to learn from experience, and to interact with each other and with us in new and unexpected ways.

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