Title: An overview of robotics and newer applications

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Abstract

This article presents three newer areas where robots are being used. The choice of areas is purely that of the author as there are numerous other areas where robots are being increasingly used. The article is an overview and attempts to present the science and technology behind these newer robotic applications.

Introduction

The subject of robotics and robots themselves have fascinated engineers, scientists, and the general public equally for many years. This is perhaps due to a desire to create `human-like' machines that can perform tasks that humans do not like to perform or cannot do efficiently for extended periods of time. Although major efforts are underway across the world towards creating intelligent robots capable of performing autonomously or at the command of humans, the goal is far from being achieved. The field of robotics itself is fairly new – the modern industrial robot was patented by George C. Devol in 1954 (he called it a `*Programmed Article Transfer*')[1] and then J. Engelberger and George C. Devol founded the world's first robot company, Unimation Inc., in 1956. The first industrial robot from the company, called *Unimate*, was purchased by General Motors for installation at an automobile plant in New Jersey, USA, in 1961 to handle hot die cast components. Since then, a huge variety of robotic devices and their widespread applications, in almost all areas where machines enter our society, have come into being. Nowadays robots find extensive usage in factory environments, in hazardous environments such as deep sea, nuclear reactors and outer space and, recently, in new areas such as homes, robotic surgery, service sector and for entertainment. In fact, it has been claimed that we are in the midst of a *robotics* revolution, and this revolution, together with rapid advances in associated areas of electronics, controls, sensing, and computing, will have more influence on human society than the Industrial Revolution of the 17th and 18th centuries. In this article, a few interesting robots, the science and technology behind them and their applications are presented.

Industrial Robots and Cobots

Modern industrial robots have been employed in large numbers in tasks that are repetitive, backbreaking, and also boring for human beings. In these tasks, human beings cannot maintain the required accuracy or quality because of the monotonous and tedious nature of the task. Typical applications can be seen in automotive industries where robots are often used for spray painting and welding of car bodies, in general manufacturing where robots are used for loading and unloading of material, parts, and tools from other machines, and more recently for assembly of components. Most industrial robots are what is known as *serial robots* with a fixed base, joints and links connected one after the other and ending in a free end-effector or a tool. A general-purpose industrial robot has six-degrees-of-freedom (or six actuators) required to arbitrarily position and orient an object or a tool in 3D space and comes with specialized end-effector or tools for various tasks. It has been known for a while (see, for example, the work done by the Fraunhofer Institute of Manufacturing, Germany [2]), that a robot fits nicely between a purely manual and an automated transfer line or fixed automation. It was shown that the cost per unit for manual work-cell remains more or less same while the cost for a robotic work-cell decreases from a larger value and there is a breakeven point (around 5000 units in reference [2]) where the cost of a robotic work-cell is lower than manual manufacturing – the cost per unit in fixed automations is less than for a robotic work-cell when very large (greater than 100,000 in reference [2]) number of units are manufactured. On the other-hand the flexibility decreases from manual to robotic work-cell to fixed automation -- it is very expensive and time consuming to change a fixed automation if the product look, design and features changes to keep up with changing consumer taste. In the same study [2], it was shown that a hybrid automation, consisting of a robot and manual manufacturing, increases flexibility and the breakeven point for cost is lowered from that of a robotic work-cell (to around 1000 as per [2]). A robot working with a human being in close proximity is often called a *cobot* or a collaborative robot and the first cobot (patented in 1997 as an *Intelligent Assist Device* [3]) came out of funding by General Motors. A robot working with human beings needs to be designed very differently than a typical industrial robot. First and foremost, it needs to be inherently safe for the human and meet relevant exacting safety standards. Second, it needs to be of light-weight construction with smooth rounded links, user friendly operations and finally, it is equipped with large number of smart sensors for control and to achieve the safety and operational requirements.

Cobots have found usage in various areas other than in manufacturing – they are being used in minimally invasive surgeries, physical rehabilitation of injuries and in wearable robots (or exoskeletons). A robotic system called *Da Vinci* [4] has been used for remote surgery, where it is programmed to follow the physician's hand movements very accurately and with less tremors (the tremors and unwanted movement can be removed with the help of a computer and the robot controller), and thus can be used to perform very delicate surgeries over very large distances and thus the surgeon’s skills are available to patients in remote areas. In rehabilitation, the person needs to move and exercise his/her arms legs periodically over several days/weeks to recover strength and movement range and a cobot can be used to replace a physiotherapist. An exoskeleton or a wearable robot can be used to lift/manipulate very large weights, not possible physically by a person, when required. There are several manufacturers of cobots such as UR10 and KUKA to name a few [5,6]. One can expect many more applications of cobots to be developed in future.

Robots in Space – Space station and JWST

A natural area of robot usage is in an environment that is hazardous to humans, or an environment where the cost of protecting a human is very high. A well-known example was the Canadarm (Shuttle Remote Manipulator System) used in the space shuttle missions for more than 30 years, to deploy satellites and experimental payloads from the cargo bay with the astronauts safely inside the cabin [7]. It was later combined with a sensor system to inspect the exterior of the space shuttles for damage to thermal tiles in the exterior of the space shuttle. The Canadarm was a six degree-of-freedom serial manipulator of mass of 410 kg and of total length of about 15 metres and could manipulate objects originally up to 29,000 kg which was later upgraded. The Canadarm is an extreme example of *lightweight and flexible robotic arm* – on ground the manipulator would deform due to its own weight and its motors would not be able to lift the arm itself. For training the astronauts to operate the Canadarm, extensive simulation and a model was created. An improved manipulator arm with seven degrees-of-freedom and longer reach of more than 17 metres is now in use in the International Space Station (ISS) [8]. This is used to move large segments of the ISS into place, capture unpiloted service crafts, berth and release spacecrafts from the ISS and can move from one place to another in the space station (in an inchworm like movement) to inspect the exterior of the ISS for any damage. A similar arm design is being explored for the Bharatiya Antariksh Station – an orbiting space station being planned by India and expected to be operational by 2035.

Another class of space applications is for docking and accurate pointing of mirrors and instruments for scientific applications. A well-known six-degree-of-freedom *parallel manipulator*, namely the *Gough-Stewart platform* [9], has been extensively used for such applications. A Gough-Stewart platform consists of a fixed base and a moving platform connected by six extensible legs. By extending or retracting the legs, the top platform can be positioned and oriented in 3D space as desired. The two key advantages of a parallel manipulator are that the load carrying capacity is much larger as the load is shared by six supporting legs, and the positioning and orienting error of the top platform is the maximum error in any of the legs (in a serial manipulator, due to the sequential structure of joints and links, the errors at the individual joints add up at the end-effector). As the spacecraft approaches the space station, the capture is done by a docking mechanism [10] which is based on a Gough-Stewart platform. The main reasoning is that the misalignment (in terms of positioning and orientation) of the approaching spacecraft with the docking port of the space station at the final stages can be corrected more easily by the Gough-Stewart platform and the whole spacecraft need not be moved by using thrusters. Once the approaching spacecraft is in contact with the space station, a second set of latching mechanisms are used to ensure that the arrangement is airtight and safe, and cargo and astronauts can be transferred from the space station to the spacecraft and vice-versa. A Gough-Stewart platform-based docking is also planned for the Bharatiya Antariksh Station.

A very new application of a parallel Gough-Stewart platform is the James Webb Space Telescope (JWST) (see, a popular explanation in [11] and more formal one in [12]). The JWST has 18 hexagonal mirror segments which when properly aligned form a single 6.5 metre diameter mirror which can then view and image extremely distant stars and galaxies in the infra-red. Each of the hexagonal mirror can be positioned and oriented by a Gough-Stewart platform at the back and additionally there is a seventh leg/actuator which can deform the mirror to get even better orienting/focussing capability on the mirrors. The images obtained by JWST is revolutionizing astronomy and much more is expected during its lifetime.

Gough-Stewart platforms are ideal for vibration isolation – a sensitive optical or other payload on a spacecraft can be isolated from vibration arising in the body of a spacecraft from rotating components and thrusters – and the functioning of a payload on the spacecraft can be significantly improved. Significant amount of work has been done in this regard (see, for example, [13, 14, 15] and the references contained therein), and very recently a new two-radii modified Gough-Stewart platform has been proposed [16] where the first six modes of vibration can be very effectively reduced either passively or using active control. Experimental evidence show that such a two-radii modified Gough-Stewart platform gives much better vibration isolation capability.

Bipeds and Quadrupeds

Wheeled mobile robots can move very efficiently on flat terrain since the ideal rolling of wheels without slipping is a very efficient means of locomotion. On uneven terrains, walking allows more flexibility to negotiate the unevenness and robots with legs are better suited for uneven and unstructured terrains in comparison to robots with wheels. Numerous legged robots, with two and four legs have been developed all over the world in research labs and by companies. Some of the well-known ones are the very famous humanoid robot ASIMO [17] by Honda, robots used in RoboCup [18] games held every year and quadrupeds such as Mini Cheetah developed by MIT or BigDog by a company in USA [19]. A biped robot with a humanoid form has many advantages – the robot and the human can interact more naturally, the human-like body is suited for navigating in typical inhabited environment with stairs, narrow corridor, door handles etc. and, in general, an anthropomorphic biped robot can work better in environments designed for humans. In space explorations, specifically in a spacecraft, biped and humanoid robots are expected to perform well with humans and Robonaut-2 [20] is a special case of a biped design to best suit the environment on the International Space Station (ISS). Biped robots have been proposed for many other applications such as in rescue missions, industrial robot for hazardous working conditions, as help at homes and for interaction with humans in the service sectors.

A quadruped is simpler to control as it can be inherently stable and can perform many of the locomotion tasks done by a biped. Significant amount of work has been done on developing hardware and control algorithms for a quadruped and recently modern AI/ML based approaches, such as reinforcement learning, have been applied for learning about the flexibility in the spine and for optimizing the trajectories of the legs (see, for example, [21,22] and the references contained in them). Research on quadrupeds and bipeds are being actively done by numerous universities and companies worldwide and they are expected to be more commonly seen in industry and society.

An Overview of this Issue

Please add an overview of the papers appearing in this issue.

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