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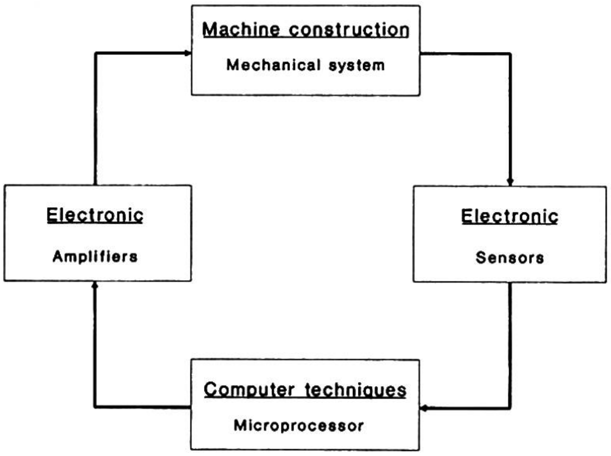
Mechatronics

Mechanics is a classical science; statics has had a solid scientific basis since antiquity, and dynamics since Newton. Electronics began with the invention of the amplfier valve in the year 1908; for four decades, however, its use was limited to communication techniques. It was only with the invention of the transistor in 1947 – before the integrated circuit (IC) in 1960 and the microprocessor in 1978 – that the locks opened to a flood of new uses affecting practically every aspect of human life. The expression «mechatronics» signifies those systems in which mechanics and electronics are indivisibly connected.

The best-known robots and also most significant realisation of a mechatronic system is the industrial robot. Its inventor must be regarded as George C. Devol, an American who in the early 1950's took out a series of patents involving the combination of the two known elements of remote controlled and numerically controlled manipulator. He thus laid the foundation of mechatronics, which then sparked a technical, economic and social revolution. Strictly defined, not every handling machine is a robot; this word should be reserved for manipulators which have at least four degrees of freedom (i.e. four independent joints) which can be freely programmed. This definition is not, however, always strictly observed, and so information about the number of existing robots may be questioned. One can assume, however, that world-wide, there are far more than 200000 robots in operation, one half of them in Japan, and that this number is increasing rapidly.

An industrial robot has three main parts: the basic body (manipulator), the drive, and the control. The basic body and the drive form one design unit. Both consist of classical elements of machine design and hydraulic, pneumatic or electrical drive techniques.

The last two decades have brought many improvements, but no basic changes, and none are expected in the foreseeable future. The stormy advance of robots is determined by advances in the third part, that is, in the controls. It is the possibilities contained in microelectronics which are here being used to the fullest. Depending upon its flexibility, the industrial robot can carry out a great variety of tasks, and it is difficult to overview the number of uses which have been attempted.



A mechatronic system picks up signals from its surroundings, processes them, and reacts outwardly with energy and movements. Characteristic are both the closed feedback circuit and the fact that a significant part of the system consists not of the hardware, but of the software.

A small number of applicatios have proved themselves particularly successful, and these dominate the robot scene. The majority of robots in use today, as effective mechanism are graspers and carry out the following sequence which can be called «pick and place». An object is grasped, brought to a new location, deposited, and released. What is often involved here is assembly, that is, the putting together of individual parts to make up a complcated part. Not every assembly task which can be carried out by the human hand is, however, suitable for a robot, and thus it is often necessary to alter machine parts to make them usable for robot assembly.

It is the automobile industry which, among other industrial branches, has made the widest use of robots. Two uses of robots have been particularly successful: welding and the spray painting. The great number of welding operations in an automobile can be carried out by robots quickly and exactly. A spray pistol is used for painting; this is directed back and forth by means of a constant track control. A robot does not carry out this work better or more rapidly than a human, but more evenly.

A works manager remarked that a robot could paint as well as the best worker on his best day.

Closely connected with the utilisation of a robot is the task of programming. In order to be considered a robot, it must be possible to program a handling machine freely, that is it must be possible to change its task without altering any electrical or mechanical parts. «Programming» means that a person lets a machine know his intentions. How should he make himself understood? One can program simple robot tasks, in which a series of specific fixed tasks occur, in that one feeds in the coordinates of these points as numbers. A totally different method, which can serve as an example for many other cases, is used in spray painting. An experienced painter carries out the act of spraying, by hand, in a manner he considers best.

A suitable device conveys this movement to the robot, which stores both the path as well as the velocities. This kind of programming is, however, inflexible; it is difficult to make small changes in the stored program. Robots of the first generation have the common charcteristic that they carry out a movement according to a fixed program, and that they do not have the ability to make observations in their fields of action and then react to them. The great majority of manual routine jobs which a human can carry out without difficulty are beyond the ability of these robots because humans also use their eyes and sense of touch. Robots of the second generation pick up visual and tactile signals from their field of action and use this information to make corrections in the course of their motion. It is not very difficult to place a pressure sensor on the clamping area of a gripper and to convey the measured pressure to the controls, but this achieves very little. A good number of pressure sensors must be used to effect a real improvement.

The picking up of visual information begins with a single ray of light which is interrupted and thus shows the proximity of an obstacle, and goes on to a video-camera which picks up a complete picture of the scene of action, digitizes and analyses it using the latest computer methods. The problems of creating such «intelligent robots» concern both hardware and software; they are demanding but highly rewarding improvements in the field of robots. In the next ten years developments will primarily come from this domain.

«Advances in robotics» is today practically the same as advances in sensors, image processing, microelectronics and informatics.

The Essence of Mechatronics

Robots are the best-known but certainly not the only application of «mechatronics» which covers a far greater area of uses. The designation «mechatronics» probably arose in Japan, and today is also widely in use both in French and in German speaking countries, but not, however, in the English-speaking world, where the expression «information-driven mechanical systems» is used. Mechatronics is an interdisciplinary field of the engineering sciences, building on the disciplines mechanical engineering, electronics and computer science. A mechatronic system picks up signals, processes them, and thereby creates new signals which it converts into energies and movements.

Such a system is not just an ordinary machine which has been supplied with electronic controls, and thus it is incorrect to designate a traditionally-made handling machine as a robot. A mechatronic system is a unit in which the mechanics and electronics are closely related in the closed feedback loop; important also is the high degree of system-knowledge and software necessary for both the construction and use. It is absolutely justified to speak here of the software as a machine element. A key element is the microprocessor; without doubt the most important event in the history of mechantronics until now has been the emergence of microprocessors.

Robotics is an interdisciplinary field, and therefore makes great demands on an engineer. Whoever wishes to work in an interdisciplinary field cannot avoid learning the basic disciplines first. It is an illusion to believe that one can begin one's education by starting with the interdisciplinary fields. Therfore, a solid education in mathematics, physics, computer science, electronics and mechanical engineering is necessary at the beginning. Specialised knowledge is built upon that, and it must include computer-aided kinematics of tensors, motion equations, coordinate-transformation, multi-jointed mechanisms, electrical drive techniques (construction, various motor types, energy source equipment) robot dynamics (basic concepts and construction types, time-optimal controls), microprocessors (calculator structure, programming, A/D and D/A converted, real-time programming), control theory (sequential controls, condition controls, stability) software tools (rough draft, detailed draft, user interface). Added to these are areas from image procesing (pattern recognition frame highlighting, sensor distribution, artificial intelligence).

The fact that a significant part of the functionality of a mechatronic system is contained in the software lends great importance to the way in which the software is ordered.

Programming techniques in the field of mechatronics therefore have become an independent specialised field in itself. Its purpose is to free, as for as possible, the programmer from special informatics knowledge by the preparation of a user-friendly programming background.

A post-doctorate course in mechatronics is given at the ETH, Zürich, as well as an institute-like mechatronics group; its lecturers and members come from the division for mechanical engineering (III A) electrical engineery (III B) and computer science (III C).

These structures are a confirmation that interdisciplinary cooperation can both function and be fruitful.

If one observes the rapidly changing fields of mechatronics, one cannot ignore «artificial intelligence». Apart from the unfortunate choice of name and the fuzzy description of the subject, there are aspects of artificial intelligence which have achieved great practical importance. To these belongs, first of all, computer vision, that is, the recognition and interpretation of scenes. The recognition and grasping of objects which are a part of a limited and clearly defined assortment is a problem which has already been solved. The more general problem, however, of selecting and taking a non-standardised object from a disordered box under uncontrolled light conditions, is far from having been solved; a task, moreover, which offers no difficulties for a human laborer.

Further Uses

Robots are the most wide-spread and best known realization of the mechatronics concept, but by no means the only ones. Several examples are given here to illustrate the great spectrum of further uses. The anti-blocking system in automobiles is based upon the following question: «How should the braking power of four wheels be determined so that an automobile comes around a corner safely while braking?» This is a problem of synthesis, and it is the solution of this problem and its consequent realization by means of mechatronics which led to the antiblocking system. The automobile industry also makes use of mechatronics in other ways, for instance in the controls for electronically regulated ignition, and for the running of three-way catalysts. A substantial reduction in the emission of pollutants cannot be conceived without the concept of mechatronics.

A particularly interesting field is magnetic bearings. It is well known that rotating parts are able to be supported, fully contact-free, by magnetic forces. It is impossible, however, to solve such a problem only with permanent magnets, as there is no arrangement which is capable of damping instabilities, and thus the controls of an electromagnetic feedback loop must be employed. In addition besides mechanical building elements, electronic components such as sensors and output amplifiers, a control in the form of a microprocessor as well as an ever increasing portion of software are needed, which in the long run determine the «intelligent» use of the system.

There are a number of special areas which benefit considerably from magnetic bearing techniques. Among these are machines to measure volume and clear space techniques where contact-free bearings are of great advantage, and where there are machine tools with a great number of revolutions, and centrifuges.

An important characteristic of magnetic bearings is their ability to damp vibrations, whereby it is possible to totally overcome the problem of critical numbers of revolutions per minute. It is also possible, by means of such an arrangement, to free a rotating machine with conventional bearings from such critical revolutions per minute.

Magnetic bearings is one of the special fields of the Mechatronics Group at the ETH Zürich. Finally, the entire field of CIM (computer-integrated manufacturing) must be mentioned. A factory systematically built up along CIM lines contains both stable and mobile robots and numerically controlled machines, and, basically, is a single, highly complicated mechatronic system.

The Japanese have used the word «mechatronics» more freely than the Europeans.

If one included, in the concept of mechatronics, everything which brings mechanics and electronics together, ignoring the charactersitics of a closed feedback loop and the high proportion of software components, the circle of mechatronics becomes still larger.

Oscillator quarz would have to be included, a device for which already well over 100 million have been produced, as would the step motor in electronic watches with analoge dials, as well as the entire computer periphery with its printers, disks and laser printers.

The surface wave filter which employs mechanical waves in a crystal for microwave technics, must also be mentioned. Its production is based upon the etching technique which was developed to an extraordinary degree of perfection as a means to IC fabrication.

These same methods make it possible to produce micro-mechanical sensors for force, pressure and acceleration which offer previously undreamed of possibilities for the science of measurement.

Economics and Social Effects

The influence of mechatronics on both spheres of human activity – in industrialized countries – work and free time – has been enormous, unsurpassed by any other form of technology. Entire industries – such as the watch industry – have been totally transformed. Both the mechanical and electro industries have been completely renewed. More and more work is shifting out of the factory into the office, from machine tools to the computer workstation. The difference between factory and office worker is becoming blurred, not only as regards terminology, but also in reality. There can be no doubt that the most important impulses in this direction have come from the Japanese.

The development, the employment and the operation of robots are procedures particularly suited to the capabilities and mentality of Japanese engineers and factory personnel. To this comes the general conviction that a further development of technology and industrial production is indispensable if a country's problems are to be solved. Western countries have more reservations about mechatronics, and there is an ever growing feeling that robots and chips are job-killers. But a glance at the real economic processes clearly shows that it is not technological advances which endanger jobs, but rather their neglect.

It is important to remember that it is the transistor, the electronic basis of mechatronics, which brought about this technical revolution. there can be no doubt that this invention must be included in the first rank of secular events. And what will the future bring? It is clear that there will be rapid development in machine technology. Sensors and visual systems will provide important impulses.

The limiting factor will not lie in microelectronics, which process these signals, but in the software required for this purpose. Already today the ability to produce sufficient amounts of high quality software is far behind what microelectronics is able to process. this disparity will not decrease in the near future, but rather increase.

A tendency which can clearly be forseen is the mounting of machine elements, drive-motors, and sensors. It is already possible to obtain a robot with bending arms with remarkable characteristics: jointed limbs with 7 degrees of freedom, graspers with 10 further degrees of freedom, working hands with a capacity of over 20 kg, acceleration of over 10 g, drive-motors integrated in jointed limbs, graspers with numerous sensors for pressure, thrusting force and temperature, interface for data connection to a large parallel processor, total weight 4 kg, life-expectancy up to 100 years. The expert will object that this is a false report, that such a thing is impossible considering our present state of technology. But let him reconsider: what is written above is a description of the human arm.

Indeed, nature is far ahead of technology. But it has taken millions of years for this development. in contrast to this, technology advances rapidly. For one step for which an engineer took 10 years, nature took 1 million times longer. Inspite of that, the solutions which were found by nature can never be duplicated by technology.

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