Modern Automation and Robotics - Equipment and Methods

Joshua Dayan

Mechanical Engineering Department

Technion - Israel Institute of Technology

Haifa 32000, ISRAEL

Abstract:

The term AUTOMATION is a very general one and it covers a wide area of various subjects and related topics. It may include: low cost equipment, which may perform some simple sequence of operations; more sophisticate binary automation with binary sensors and some feedback, using binary switching equipment; programmable logic controllers; etc. The whole field of CONTROL is often considered as part of the general field of automation and the special control branches of NC, CNC, CAD/CAM, CIM and ROBOTICS are certainly parts of it. Even the general field of FLEXIBLE MANUFACTURING, is identified by automation. Using automation means the use of wide variety of equipment that fall into three categories: actuators for the output of the automated system, sensors for the input functions and computational devices (simple circuits consists of binary gates or sophisticated computers capable of carrying out complicated computational tasks), that determine the action to be taken and the timing. The methods used in various types of automation are also quite diversified and may differ from each other in the basic mathematical foundations, in sophistication and in the equipment they are operating.

In this paper we review the most important general issues in modern automation and briefly summarize the different equipment and methods that are commonly being applied where-ever automation is practiced.

1. Introduction:

In this paper we attempt to review and classify the various types of automation and automated systems we encounter in daily life: at home, in the office, transportation systems (in ground, air and water), in vehicles and traffic control, in the processing and manufacturing industry and in military systems, of course. Automation is a very general concept and it may equally apply to a simple device performing some sequence of primitive actions as well as to a very complicated system combining complex apparatus and machinery "automatically" performing sophisticated tasks. Usually, the term "automation" is used to describe a process, or a sequence of actions, being controlled by a predetermined or preprogrammed logic, embedded in the system, with no "manual" or human intervention beyond "pressing the START button".

We start with a short overview of the devices commonly used as actuators, sensors and power suppliers for what is usually referred to as "Low Cost Automation". Then, we consider the basic methods used to design these automated systems. Briefly, we cover some miscellaneous elements and special purpose system and, then, summarize the main aspects of semiflexible and flexible automation. These lead us to discuss the subject of Assembly Automation and last but not least the role of Robotics in automation. Many of the examples and illustrations that will be shown during the lecture are taken from Pessen [1989].

2. Power Supplies, Actuators and Sensors.

Simple, low cost automated systems are based on binary, "sequential" control, using (binary) logic elements. The most common systems are based on mechanical mechanisms, pneumatic and hydraulic circuits, with some electric or electromechanical parts.

Power supplies and actuators: the power and "mechanical motion", in this kind of automated systems, is usually supplied by electric motors, DC, AC or step motors. They all provide "angular" motion ("rotation"). To convert into other types of motions we use "actuators".

Intermittent Rotary Motion is achieved by either Geneva wheel mechanism (for relatively large steps), or by the use of step motors.

To convert rotary motion to linear motion, three possible "converters" are available: Rack and Pinion, Ball Screw and Slider-Crank Mechanism. It is also possible to obtain linear motion by use of electric linear actuators, such as Linear Induction Motors or by Solenoids. (The latter provide only limited motion).

Another type of actuators derives its power from Fluid Power, i.e., a pressurized fluid drives linear or rotary actuators, such as:

a. Steam engine and air motors - full rotational motion

b. Many different actuators providing limited rotary motion.

c. Pneumatic or hydraulic linear cylinders.

Sensors: Next, our automated system requires some sensing ability to provide information such as whether a certain "position" or "state" has been reached. The common practice is to equip the system with Binary Sensors yielding on-off signals. There are endless different kinds of such sensors utilizing a great variety of physical principles in their operation. Only a modest list of the most common ones is given below:

a. Limit switches - electric or pneumatic/hydraulic - opening or closing the circuits.

b. Mercury Switches - elongated glass tubes partially filled with mercury providing "contact" by tilting the tube.

c. Photoelectric sensors.

d. Ultrasonic sensors.

e. Proximity sensors - inductive; capacitive; magnetic and many others employing different effects.

d. Sensors for physical variables other than "position", such as Level, Pressure, Temperature, etc.

3. . Switching Theory and Switching Elements:

In the heart of every automated system we have the "Control" system, or the "Logic", which generates the proper command at the proper time. The design of the control for most of the existing automated system is based on the Switching Theory, utilizing Boolean Algebra (e.g., Marcovitz & Pugsley [1971], Kohonen [1972], Zissos [1971]. Switching theory deals with binary variables, having "Logic 0" or "Logic 1" values. The various "functions" relating these variables to each other, are called "Gates" (NOT, AND, OR, XOR, NOR; NAND, INHIBITION, FF).

The basic Boolean algebra theorem, or operations, are:

$0 \cdot 0 = 0$

$0 + 0 = 0$

$1 \cdot 1 = 1$

$1 + 1 = 1$ (not 2!)

and the "Negation" operation: 1'=0; 0'=1.

Everything else essentially stems from these basic operations.

By designing a "Good" switching control circuit, involving large number of variables, we usually mean minimizing the number of gates, in order to simplify the operation and to reduce the possibilities of malfunctioning or failure. Clearly, reducing the number of elements, also increases reliability. One can use Analytical Simplification and Truth Tables for reducing functions of small number of variables, Karnaugh-map method for up to 8-variables and Quine-McCluskey or other numerical methods for larger number of variables.

Switching elements - hardware: The hardware realization of the various "gates" in industry is based on several different physical effects. We briefly discuss here, the following techniques:

a. electronic logic gates

b. Relays

c. Pneumatic valves

d. Pneumatic moving-part logic

c. Fluidic elements.

The electronic Gates are based on one of the following technologies: RTL - (Resistor-transistor logic); DTL - (Diode-transistor logic); TTL - (Transistor-transistor logic); CMOS-(Complementary metal-oxide semiconductor). They are available in "chips", integrated circuits (IC), of different degrees of integration (SSI, MSI, LSI and VLSI). Typically, the power consumption and power output of ICs is very low (mW), thus connecting a control circuit constructed of "chips" to the automated system is done through Input/Output Modules, that provide the proper transfer of signals in the system (in spite of the power discrepancies among its various parts). Since the '80s, power integrated circuits (PIC), ICs consisting of both logic and power I/O's, are also available.

Relays are used in the control circuit to isolate between the command input and the actuating output. They may operate multicontacts with different characteristics (NC or NO contacts carrying different levels of currents at the same time). The most common relays are the electromechanical (EMR) relays but other types, such as Reed Relays or solid-State Relays (SSRs), are also frequently used.

Pneumatic (and/or hydraulic) valves are used in systems with pneumatic (hydraulic) actuators for switching and sensing. A valve may have two or three positions (the third is the "Neutral" position) with 2 - 5 input and output tubes connected to it (the symbol "5/2 valve" means that the valve has 5 tubes connected to it and it may stay in two distinct states). The command to the valve, causing it to switch states, may be mechanical, pneumatic or electrical. In addition, the valves may be equipped with returning springs. Obviously, to supply the power, pneumatic automation requires air compressors while hydraulic automation requires pumps and hydraulic fluid circulation tubing.

A certain type of pneumatic valves, called Moving-Part Logic (MPL) Elements is used to perform logic gates operation, similar to the electronic gates.

The Coanda effect (Henri Coanda, 1932) is used to interact small air jets in Fluidic Elements. With proper design all logic functions can be built from rather cheap and simple-constructed fluidic elements. However, although they seem to have the potential to beat the electronic logic gates they never did. Today, they are found only where electronic devices are considered hazardous.

4. Control Design for the Automated System.

For pneumatic or hydraulic automated systems we may use switching theory in order to reduce the number of variables and gates needed for the operation and, then, implement it with the use of logic gates. The type of technology to be selected for the implementation (electronic gates, fluidics, etc.), depends to a large extent on the nature of the process (hazardous limitation) and primarily on economics. We discuss here some of the leading methods of designing control schemes for "low cost" pneumatic and/or hydraulic automation.

Ladder diagram: Probably the most common technique in low cost automation is the use of electric control, employing relays, solenoids and limit switch contact, to drive the pneumatic (and/or hydraulic) "pilot" valves. The later provide the necessary switching and direct the power to the designated actuators at the right time.

Three different methods are used with the so called Ladder Diagram design: sequence chart, cascade and Huffman. The first is not very systematic and depends to a great extent on the designer's skill and ingenuity. The second (cascade) method is quite systematic and always leads to a workable solution even for large systems. However, the designs are not optimal (number of components may be larger than the required minimum). The Huffman method (Huffman [1954, 1957]) is not easy to master but it always results in minimum number of relays. It is considered to be the "classic" method of ladder diagram design and is suitable for systems with random inputs, too.

Pneumatic Control Design: It is also possible to utilize the previously described pneumatic elements to build the control scheme. Doing so, the entire system is pneumatic (hydraulic) with no need for interfacing and conversions as required if electric equipment and the ladder diagram technique is used. However, in most cases the resulting all-pneumatic system is more expensive than the equivalent system with electrical control.

The Sequence-chart, the Cascade and the Huffman methods, that were used for the ladder design, are also suitable for designing pneumatic control circuits. In addition, there are other design methods for pneumatic schemes. These are: Cole method (Cole [1968]), Cole & Fitch [1969], Fitch & Surjaatmadja [1978]); Pessen method (Pessen (1983,4]); Bouteille method (Bouteille [1973]), Cybergram method (Holbrook & Chen [1984]).

5. **Miscellaneous Elements:**

In modern automation we encounter additional elements as well. Many installations require timers (On or Off delays that can be mechanical, electrical or pneumatic), triggers and pulse shapers, flip-flops (R-S, J-K and Trigger FFs), encoders and decoders. These, together with various logic gates are combined to sub-systems such as counters, shift registers, comperators, A/D and D/A converters, latches, buffers, etc. A more advanced degree of integration yields various I/O cards for controllers, micro-processors, micro-computers and full-size computers. These are used as the basic construction elements for advanced control systems and flexible automation.

6. **Semiflexible and Flexible Automation:**

The "flexibility" in automation means the ability to reassign new tasks to existing equipment, change the sequence of operation for different elements, or, in other words, to "reprogram" the system.

Limited capability of programming, where switches may be triggered to operate at different times, is found in several types of stepping switches (drums carrying removable/displaceable pegs) or, rotating-cam limit switches. To the same category we may add programmable Timers, Cards and Tape Readers, Programmable Counters and Matrix Boards (Cards & Tape Readers as well as Matrix boards are essentially obsolete!). Some examples of these elements are discussed by Pessen & Huebl [1979], Kumar [1981] and McCord [1983].

Modern automation systems require much higher degree of flexibility. This is usually achieved today with PLCs (Programmable Logic Controllers) and with control computers. Modern PLCs consist of software-based general-purpose equivalent of relay panel, timers and counters. In addition they may have "analog" input/output capabilities, similar to continuos variable controllers. PLCs are programmed through a special "Teach" device, which loads the program into their memory or, through a much more friendly-user computer interfacing link (the design of the control program is made on a PC and "loaded" into the PLCs). For the design the Ladder Diagram method is usually employed, together with a simplified version of the BASIC programming language. Since all switches and relays are software elements (virtual elements) there is no sense in investing too much effort in minimizing the number of these elements. Modern PLCs may support a few thousands of software relays and solve almost any realistic problem. In practice, the number of variables that one PLC supports is usually determined by consideration of safety, reliability and decentralization of the control - not by its software limitations. Since the PLC is a "digital" computer-like instrument it needs I/O modules to convert the input and output signals it reads and generates.

Continuous variable control such as industrial control of flow, level, temperature and pressure, my also be considered to be "covered" by the general term "Automation". However, we will not discuss it here and concentrate primarily on the type of automation which leads to manufacturing and assembly.

7. Assembly Automation

Perhaps the most fascinating application is the automated assembly line, whether it is baby toy assembly or car manufacturing. This kind of automation reached a very high degree of development. In many applications a complicated machinery is being assembled in seconds, with no human intervention. If performed by human workers the same task may take hours or days. Moreover, where accuracy is important the human workers sometimes cannot provide the requirements at all.

The assembly process begins with feeding the various parts to the exact location, at the exact time and correct orientation, where they are picked and loaded properly, by the automatic assembly machine. The feeders performing this feeding tasks are an important link in the whole process. Sometimes they are very "intelligent" in selecting only the correct parts and setting it in the proper orientation for the next stage. There are vibrating and non-vibrating feeders and their design is usually adapted to the particular part they are handling. A different set of machinery is handling the part-transfer from the feeder to the assembly location. Then, there is the "pick-and-place" unit which performs the actual assembly. In many cases, this latter unit must have manipulability capabilities, in order to reach through complicated paths and to link the particular part with the rest of the product. For such complicated tasks robots are often added to the assembly line, too.

Finally, the product usually goes through inspection and quality control (where the bad or damaged products are rejected) and, then, it is transferred to packaging and shipping. All of these are also done or can be done automatically. In many cases, the components of a product intended for automatic assembly, are especially designed for such assembly. They have to be asymmetric; they should provide handling/orienting, lips or shoulders, to help guiding them; they should be smooth to avoid tangling.

8. Robotics in Assembly and Manufacturing:

The field of robotics is considered to be the most advanced technique or technology being used in automation. It is a relatively young technology, fascinating and inspiring. In our imagination the robot is a human-like machine, having human intelligence, machine accuracy but has no inhibiting feelings. As such, it can perform any mechanical task, or operation, better than human. Unfortunately (or fortunately), the myth and the fiction are by far ahead of the reality and although there is huge advancement in the field of robotics and the robots are improving every day, they still cannot replace us in most of the things we are doing and they are very dependent on us in taking their path or action. Nevertheless, robots have been successfully employed in many complicated automatically controlled assembly systems, in manufacturing and in many other applications, on earth, in space and under water.

Robots may have different shapes and sizes according to the various tasks they are designed to perform. The most common is the articulated robot, Cartesian or polar, with 2-7 degrees of freedom (Koren [1985], Nof [1985]). They are usually equipped with a gripper at their end-effector, to hold the tool they are operating or the part they are assembling. The common gripper is a simple device, usually made of a pair of pincers applying opposite forces on the part to grasp it. Sometimes, the shape of the gripper is made to exactly complement the part it is designed to handle.

Today, robot already have their important share in automation, performing repeated tedious actions, that require accuracy and force, and that were formerly executed by humans. On the manufacturing floor we also find AGVs (Autonomous Guided Vehicles) that transport parts and work pieces form one machine to another. These are considered to be robots, too. Integrating robots in the manufacturing process requires a very intelligent computer programs to run and control them. The integration in manufacturing requires full exchange of information at real time between the NC, CNC and other sophisticated machines and the robots working around them. That means advanced network and advanced computerized management for the entire manufacturing plant. The highest degree of sophistication, today, consists of automatic loading of the CAM machinery with the output of the CAD system along with such fully automated manufacturing plant with all automatic CIM machinery, robots that load and unload parts on/off the machines, AGVs that move the work pieces, the raw materials and the products, within the manufacturing facilities, automatic packaging and automatic storage.

Other type of robots are crane-like "parallel" robots that can be found, or being thought for the heavy industry, such as construction, shipyards work, etc. (Albus [1985]; Unger [1992]). Similar type of parallel robots is the Stewart Platform type, using linear motors (Ben-Horin and Shoham [1996]).

Research and development work on general robotics control and on special elements of robotics will probably change the present picture, again, in the near future. For example, development of an artificial hand, with full capabilities, is being carried out in many of the most famous robotics centers in the world (e.g., Stanford hand, MIT hand, work in Carnegie Mellon University, etc.). It is believed that soon we will see much more advanced grippers or "hands" with tactile and sensing capabilities along with full manipulability (see, for example, Brook et al. [1997], for the latter). These kind of future robots will add another order of magnitude to the flexibility of automation, in general, and to assembly and manufacturing in particular. Control algorithms for different applications will be developed and selection methods for the best algorithm suitable for a particular job will be available (Brook et al. [1993]). Robot force control, which is also a relatively new field with rapidly developing applications, will also reach maturity soon (Hogan [1985], Shaki et al. [1994, 1997]).

9. Summary and Conclusions:

Modern automation today is an integral part of every aspect of our daily life. In this paper we have concentrated, mainly, on automation related to industry and manufacturing, although many of the techniques, methods and equipment are equally used in many other fields. We have reviewed some of the "low cost" automation methods, semi-flexible and flexible automation and special equipment. All these are still used as the basis in all modern approaches. We, then, gave an overview of automation in assembly and manufacturing, including a brief discussion of the roll of robotics in the modern industry. The paper is concluded with a brief discussion of what can be expected from robotics in the near future.

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