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ELECTRICAL AND ELECTRONIC ENGINEERING

(DIPLOMA COURSE)

POWER OPTION

MODULE:III

MICROCONTROLLER TECHNOLOGY

TRAINING MANUAL

BY

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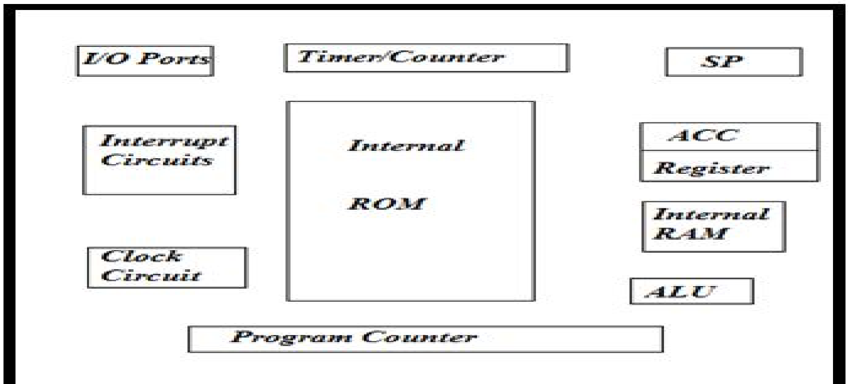
INTRODUCTION

Microcontrollers

A microcontrolleris a highly integrated chip on single chip with most of the parts needed for a controller to function. The microcontroller includes: CPU (Central Processing Unit), RAM (Random Access Memory), EPROM/PROM/ROM (Erasable Programmable Read Only Memory), I/O (input/output) – serial and parallel, timers, interrupt controller. Intel 8051 is 8-bit microcontroller while Intel 8096 is 16-bit microcontroller.

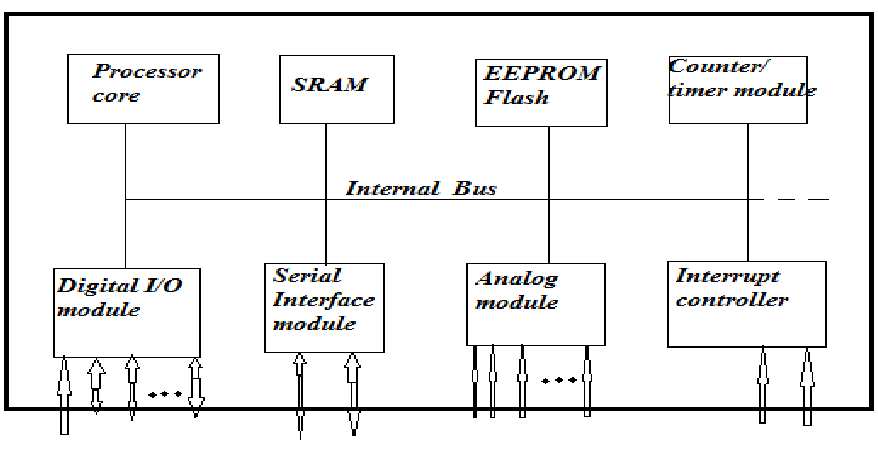


A Block Diagram of a Microcontroller

Microcontrollers offer a mechanism that controls the operation of a machine. The first microcontrollers were Intel 8048 integrated into PC keyboards, Intel 8051 and 68HCxx series of microcontrollers from Motorola. Microcontrollers perform numeric operationsthat include;

- Supermarkets in Cash Registers, Weighing Scales, etc.
- Home in Ovens, Washing Machines, Alarm Clocks, etc.
- Toys, VCRs, Stereo Equipment, etc.
- Office in Typewriters, Photocopiers, Elevators, etc.
- Industry in Industrial Automation, safety systems, etc.
- On roads in Cars, Traffic Signals, etc.

Theyare connected to the outside world through the I/O pins of the microcontrollers.



Basic layout of a microcontroller

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The following are found in microcontrollers:

Processor Core

It is the CPU of the controller and contains the arithmetic logic unit, the control unit, and the registers.

Memory

Memory is split into program memory and data memory. DMA controller handles data transfers between peripheral components and the memory.

Interrupt Controller

Theseinterrupt normal program flow in case of external or internal events. In conjunction with sleep modes, they help to conserve power.

Timer/Counter

Controllers have at least one or 2 to 3 Timer/Counters used to timestamp events, measure intervals, or count events. Many controllers contain PWM (Pulse Width Modulation) outputs which are used to drive motors or for safe breaking.

Digital Input/Output I/O

Parallel digital I/O portsvaries from 3-4 to over 90 depending on the controller family and controller type.

Analog Input/ Output I/O

Most microcontrollers have integrated analog/digital converters which differ in the number of channels (2-16) and their resolution (8-12 bits).

Interfaces

Microcontrollers have at least one serial interface used to download the program and for communication with the development PC in general. Most controllers have several and varied interfaces like SPI and SCI. Larger microcontrollers contain PCI, USB, or Ethernet interfaces.

Watchdog Timer

The watchdog timer is used to reset the controller in case of software “crashes” to ensure safety of critical systems for microcontrollers.

Debugging Unit

Some controllers are equipped with additional hardware to allow remote debugging of the chip from the PC.

Common Terms in Microcontrollers

Microprocessor

This is a normal Central Processing Unit used in communication with external devices is through a data bus.

Microcontroller

- contains all components which allow it to operate as a standalonelike; memory, various interface controllers, one or more timers, an interrupt controller and ageneral purpose I/O pins which allow it to directly interface to its environment.

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Mixed-Signal Controller

This is a microcontroller which can process both digital and analog signals components.

Embedded System

In embedded systems, the control unit is integrated into the system like in a cell phone, where the controller is included in the device.

Real-Time System

Controllers are frequently used in real-time systems where the reaction to an event has to occur within a specified time as found in aerospace, railroad, or automotive areas,

Embedded Processor

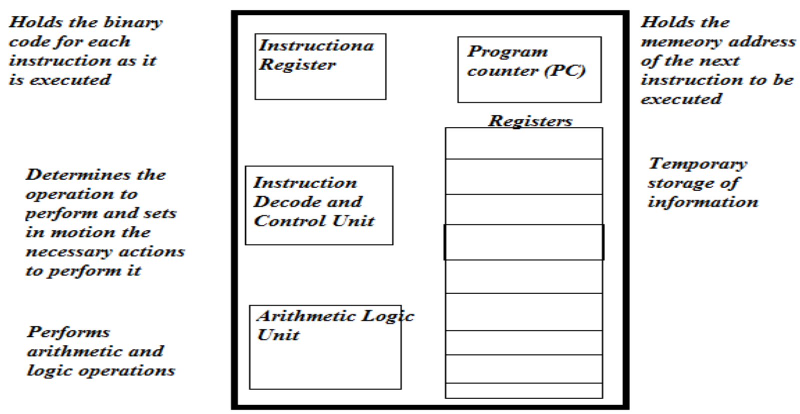
This term "embedded processor" is used for high-end devices (32 bits), whereas "controller" is traditionally used for low-end devices (4, 8, 16 bits).

Digital Signal Processor (DSP)

Digital signal processors are used to process signals like in telecommunications where a mobile phone contain a DSP andare designed for fast addition and multiplication.

Embedded Controller

An embedded controller is a controller that is embedded in a greater system.Is a controller that is embedded into some other device for some purpose other than to provide computing functions.Modern embedded microcontrollers are built using microprocessorsmaking the entire controller component to fit onto a small circuit board and contains arithmetic and logic units (ALU), Instruction decode and control unit, Instruction register, Program counter (PC), clock circuit (internal or external), reset circuit (internal or external) and registers. A CPU built into a single VLSI chip is called microprocessor with a simplified blockdiagram of the CPU shown below.



General Block Doagram of CPU

Microprocessor

A Microprocessor is general-purpose element in digital computer or central processing unit (CPU).A digital computer having microprocessor as the CPU along with I/O devices andmemory is known as microcomputer. The block diagram below shows amicrocomputer.

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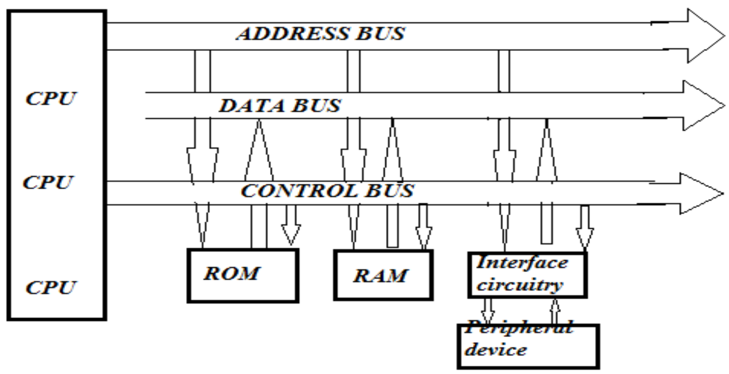

Microcomputer Block Diagram

Comparison of a Microprocessor and a Microcontroller

i. Microprocessor is a single chip CPU while a microcontroller contains a CPU and muchof the remaining circuitry of a complete microcomputer system in a single chip.

ii. Microcontrollers include RAM, ROM, serial and parallel interface, timer, interrupt schedule circuitry in addition to CPU in a single chip while microprocessorshave a small RAM in their CPU without serial and parallel interface.

iii. Microcontrollers have to respondto control oriented devices in real time using Interrupt system but this is require external components in case of microprocessors.

iv. Microprocessors are used as a CPU in microcomputer systems while Microcontrollers are used in small, minimum component designs performingcontrol-oriented activities.

v. Microprocessor instruction sets are processing intensive (*implying powerfuladdressing modes with instructions catering to large volumes of data*) while Microcontrollers have instructionsets catering to the control of inputs and outputs.

Types of Microcontrollers

Microcontrollers are classifiedbased on their internal bus width, architecture, memoryand instruction set as shown in the figure below.

i. The 8-Bit Microcontroller

This is a microcontroller that has an ALU that performs arithmetic and logical operations on a byte (8-bits) at an instruction. The internal bus width of 8-bit microcontroller is of 8-bit. Examples of 8-bit microcontrollers are Intel 8051 family and Motorola MC68HC11 family.

ii. The 16-Bit Microcontroller

This is a microcontroller that has an ALU that performs arithmetic and logical operations on a word (16-bits) at an instruction. The internal bus width of 16-bit microcontroller is of 16-bit. Examples of 16-bit microcontrollers are Intel 8096 family and Motorola MC68HC12 and MC68332 families.

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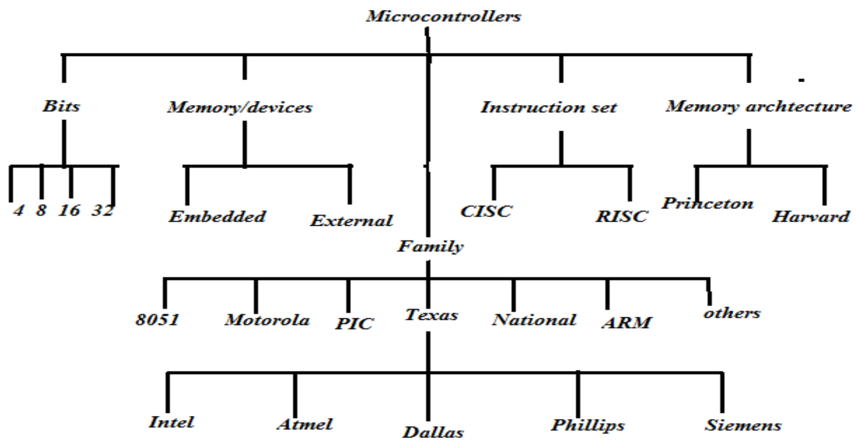
iii. The 32-Bit Microcontroller

This is a microcontroller that has an ALU that performs arithmetic and logical operations on a double word (32- bits) at an instruction. The internal bus width of 32-bit microcontroller is of 32-bit. Examples of 32-bit microcontrollers are Intel 80960 family and Motorola M683xx and Intel/Atmel 251 family.



Types of Microcontrollers

The performance andcomputing capability of 32 bit microcontrollers are enhanced with greater precision ascompared to the 16-bit microcontrollers. The 8-bit is the slowest of the three types.

Microcontrollers are grouped as either embedded microcontrollers or external memory microcontrollers as;

1. **Embedded Microcontrollers**

When an embedded system has a microcontroller unit that has all its functional blocks(including program and data memory) available on a chip is called an embeddedmicrocontroller. For example, 8051 having Program & Data Memory, I/O Ports, SerialCommunication, Counters and Timers and Interrupt Control logic on the chip is anembedded microcontroller.

2. **External Memory Microcontrollers**

When an embedded system has a microcontroller unit does not have all its functionalblocks on a chip is called an external memory microcontroller. Here all or part of the memory units are externally interfaced usingan interfacing circuit called the glue circuit. For example, 8031 has no program memoryon the chip is an external memory microcontroller.

Microcontroller Architectural Features

There are five categories of processors that differ in the way dataand programs are stored and accessed as described below:

1. **Von-NeumanMicrocontroller Architecture**

These Microcontrollers have a single (data) busthat is used to fetch both instructions and data. This means that Program instructions and Data arestored in a common main memory. When such a controller addresses the main memory,it first fetches an instruction and then it fetches the data to support the instruction later.Von-Neuman architecture has only one memory to be accessed.

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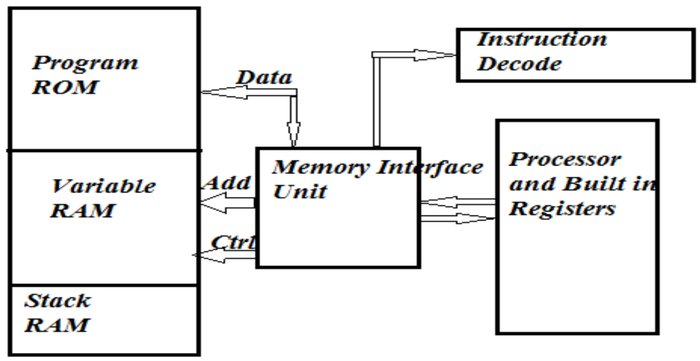
The content in RAM is used for data storage and program instruction storage, e.g. the Motorola 68HC11 series. Its Instruction is simply as "*Read a byte from memory and store it in the accumulator*" as follows:

Cycle 1: - Read instruction

Cycle 2: - Read data out of RAM and put into Accumulator

These two separate fetch processes slows down the controller's operation. The Von-Neuman Architectureis shown below:



Von- Neuman Architecture Block diagram

2. **Harvard Microcontroller Architecture**

Thisarchitecture hasa separate data bus and a separateinstruction bus whichallows parallel execution of fetch instructions. An instruction is being"pre-fetched" asa current instruction is also being executed on the data bus. Once a currentinstruction is completed, the next instruction is ready to go. The Harvard Architecture executes the same instructions through fewer instruction cycles than the Von-Neuman architectureas follows:

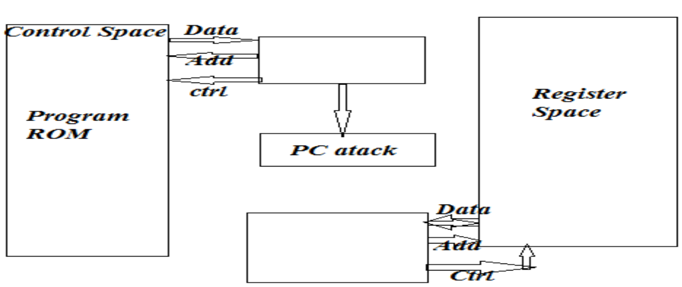
<u>Cycle 1:</u> - Complete previous instruction

- Read the "*Move Data to Accumulator*" instruction

<u>Cycle 2:</u> - Execute "*Move Data to Accumulator*" instruction

- Read next instruction

Each instruction is executed in a single instruction cycle. The Intel MCS-51 family of microcontrollers and PIC microcontrollers uses Harvard Architecture. This pre-fetch allow much faster execution of events than in Von-Neuman architecture as shows below:



Harvard Architecture Block Diagram

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3. Complex Instruction Set Computer(CISC) MicrocontrollerArchitecture

When a microcontroller has an instruction set that supports manyaddressing modes for arithmetic and logical instructions, data transfer and memoryaccesses instructions, the microcontroller is said to be of CISC architecture.Most CISC microcontrollershave over 80 instructions and perform manypowerful and specialized specific control tasks where some might only operate on certain addressspaces or registers while others might only recognize certain addressing modes.The CISC architecture has many macrolikeinstructions thatallowa programmer to use one instruction in place of many simpler instructions.An example of CISC architecture microcontroller is Intel 8096 family.

4. Reduced Instruction Set Computer (RISC) Microcontroller Architecture

When a microcontroller has an instruction set that supports feweraddressing modes for the arithmetic and logical instructions and for data transferinstructions, the microcontroller is said to be of RISC architecture.Reduced Instruction Set Computers (RISC) design is used in industries because it designs smaller chips with smaller pin counts that consumervery low power.Some of the features of RISC processorarchitecture are;

1. It allows simultaneous access of program and data.
2. Enables overlapping of some operations to increase processing performance.
3. Has instruction pipelining that increases execution speed.
4. Allow orthogonal (or symmetrical) instruction set for easy programming.
5. Allows each instruction to operate on any register or use any addressing mode.

5. Specific Instruction Set Computer (SISC)Microcontroller Architecture

Specific Instruction Set Computer (SISC) limit the capabilities of the CPU itself which then allow a whole computer(particularly memory, I/O, interrupts,…etc.) to fit on the single chip.

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TOPIC ONE
ELEMENTS OF A MICROCONTROLLER ARCHITECTURE

Central Processing Unit (CPU)

This is the brain of the computer system and it administers all activities of the system. It performs all operations on data and instructions. It performs two operations:***fetching andexecuting*** instructions because it understands data based on a set of binary codes called the instruction set.

Machine Cycle

To execute an instruction, the processor must perform the following:

1. Fetch the instruction from memory
2. Decode the instruction to understand it
3. Execute the instruction as understood
4. Store the result back in the memory.

These four steps are referred to as Machine Cycle.Generally one machine cycle = X clock cycles (where (X) depends on the particular instruction being executed). The shorter the clock cycle, the lesser the time it takes to complete one machine cycle,executing the instruction faster and hence a faster processor.

Fetching and Executing an Instruction

Fetching process involves the following steps:

(a) Contents of PC are placed on address bus.
(b) READ signal is activated.
(c) Data (instruction Op-code) are read from RAM and placed on data bus.
(d) Op-code is latched into the CPU's internal instruction register.
(e) PC is incremented to prepare for the next fetch from memory.

Execution involves decoding the Op-code and generating control signals to the internal registers in and out of the ALU.

CPU Organization and operation

The fetch-Execution Cycle

Operation of a CPU is described in terms of the Fetch-Execute cycle as follows:

Fetch-Execute Cycle	**The cycle raises interesting questions, e.g.**
Fetch the *Instruction*	What is an Instruction? Where is the Instruction? Why does it need to be fetched? Is it okay where it is? How isittracked? Where does it put the instruction it has just fetched?
Increment the	What is a Program Counter? What does it count? How much

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Program Counter	is it Incremented? Where does it point to after it is incremented?
Decode the Instruction	Why is the instruction decoded? How does it get decoded?
Fetch the *Operands*	What are operands? What does it mean to fetch? Is this fetching distinct from the fetching in Step 1 above? Where are the operands? How many are there? Where do we put the operands after we fetch them?
Performing an Operation	Is this the main step? What part of the CPU performs this operation?
Store the results	What results? Where from?Store where?How?
Repeat forever	Repeat what?Repeat from where? Is it an infinite loop? Why? How do these steps execute any instructions at all?

Representing Programs

Each complex task carried out by a computer needs to be broken down into a sequence of simpler tasks. This requires a **binarymachineinstruction** for the most primitive tasks. Consider a task that adds two numbers, held in memory locations designated by **B** and **C** and stores the result in memory location designated by **A**.

{What is in} A = [B] + [C]

This is broken down (by a compiler) into a sequence of simpler tasks or **assembly instructions**, as show below:

AssemblyInstruction	**Effect**
LOAD R2, B	- Copy the contents of memory location designated by **B** into Register **2**
ADD R2, C	- Add the contents of the memory location designated by **C**into the contents of Register **2** and put the result back into Register **2**
STORE R2, A	- Copy the contents of Register **2** into the memory location designated by **A**.

Each of these assembly instructions needs to be encoded into binary for execution by the Central Processing Unit (CPU). Let's try this encoding for a simple architecture called TOY1.

TOY1 Architecture

TOY1 is a fictitious architecture with the following characteristics:

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- 1024 x 16-bit words of RAM maximum. (RAM is word-addressable).
- 4 general purpose registers R0, R1, R2 and R3. Each general purpose register is 16-bits (the same size as a memory location).
- 16 different instructions that the CPU can decode and execute, e.g. LOAD, STORE, ADD, SUB and so on. These different instructions constitute the **InstructionSet** of the Architecture.The representation for integers will be two's complement.

The architect defines a coding scheme for instructions termed as the **Instruction Format**.

Instruction Format

Using TOY1 instructions above that are 16-bits (to fit into a main-memory word), each instruction is divided into a number of **instruction fields** that encode a different piece of information for the CPU as shown below;

Field Name	**OPCODE**	**REG**	**ADDRESS**
Field Width	4-bits	2-bits	10-bits

The **OPCODE**field identifies the CPU operation required. Since TOY1 only supports 16 instructions, these can be encoded as a 4-bit natural number. Using TOY1 above, Op-codes 1 to 4 will be given by:

0001 = LOAD   0010 = STORE   0011 = ADD   0100 = SUB

The **REG**field defines a General CPU Register. Arithmetic operations will use 1 register **operand** and 1 main memory **operand** and the results are written back to the register. Since TOY1 has 4 registers; these can be encoded as a 2-bit natural number:

00 = Register 0   01 = Register 1   10 = Register 2   11 = Register 3

The **ADDRESS** field defines the address of a word in RAM. Since TOY1 has upto 1024 memory locations; a memory address can be encoded as a 10-bit natural number. If we define addresses 200H, 201H and 202H for A, B and C, we can encode the example above as:

Assembly Instruction		**Machine Instruction**
LOAD	R2, [201H]	0001 10 10 0000 0001
ADD	R2, [202H]	0011 10 10 0000 0010
STORE	R2, [200H]	0010 10 10 0000 0000

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Memory Placement of Program and Data

In order to execute a TOY1 program, its instructions and data needs to placed within main memory. We'll place our 3-instruction program in memory starting at address 080H and we'll place the variables A, B and C at memory words 200H, 201H, and 202H respectively. For convenience, memory addresses and memory contents are also given in hex.

Memory Address in binary & hex	**Machine Instruction** OP Reg. Address	**Assembly Instruction**
0000 1000 0000 0 8 0	0001 10 10 0000 0001 1 A 0 1	LOAD R2, [201H]
0000 1000 0001 0 8 1	0011 10 10 0000 0010 3 A 0 2	ADD R2, [202H]
0000 1000 0010 0 8 2	0010 10 10 0000 0000 2 A 0 0	STORE R2, [200H]
Etc	**Etc**	**Etc**
0010 0000 0000 2 0 0	0000 0000 0000 0000 0 0 0 0	A = 0
0010 0000 0001 2 0 1	0000 0000 0000 1001 0 0 0 9	B = 9
0010 0000 0010 2 0 2	0000 0000 0000 0110 0 0 0 6	C = 6

The diagram below shows how a CPU is organized by design.

Program Counter (PC)

This is a special register thatholds the address of the next instruction to be fetched from Memory. The PC is incremented to point to the next instruction while an instruction is being fetched from main memory.

Instruction Register (IR)

The IR is a special register that holds each instruction after it is fetched from memory.

Instruction Decoder (ID)

The ID is a CPU component thatdecodes and interprets the contents of the Instruction Register, i.e. its splits whole instruction into fields for the Control Unit to interpret. The Instruction decoder is considered to be a part of the Control Unit.

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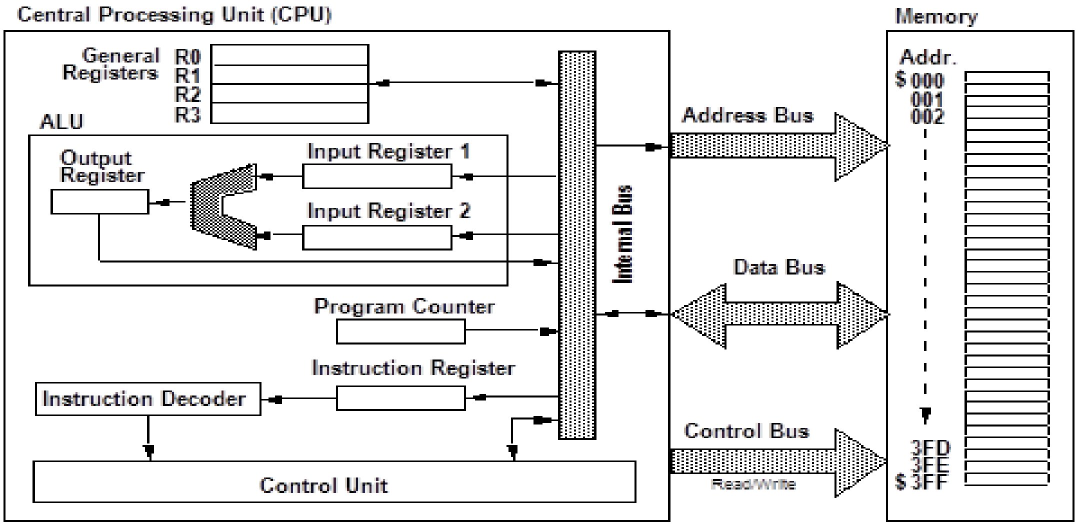

Control Unit

The Control Unit is the CPU component thatco-ordinates all activity within the CPU. It has connections to all parts of the CPU and includes a sophisticated timing circuit.

Arithmetic & Logic Unit

The ALUcarries out arithmetic e.g. addition, comparison, subtraction and logical Boolean operations e.g. AND/OR/NOT.

ALU Input Registers 1 and 2

These are special registers that hold the input operands for the ALU operations.

ALUOutput Register

This is a special register that holds the result of an ALU operation. On completion of an ALU operation, the result is copied from the ALU Output register to its final destination, e.g. to a CPU register, or main-memory, or to an I/O device.

General Registers R0, R1, R2, R3

These are for the programmer to use in his/her programs.

Buses

A Bus is a collection of wires carrying information with a common purpose. For each read or write operation, the CPU specifies the location of the data or instruction by placing an address on the address bus then activates a signal on the control bus indicating whether the operation is read or write. The Busesserve as communication highways for passing information within the CPU using internal CPU busses and between the CPU and the main memory using;

The **address bus**is used to send addresses from the CPU to the main memory; these addresses indicate the memory location the CPU wishes to read or write it carries the address of a specified location. For **n** address lines, $\mathbf{2^n}$ locations can be accessed e.g., A 16-bit address bus can access 2^{16} = 65,536 locations or 64K locations (2^{10} = 1024 = 1K, 2^6 = 64).

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The **data bus** is bi-directional; for writing, the data bus is used to send a word from the CPU to main-memory; for reading, the data bus is used to send a word from main-memory to the CPU.

The **Control bus**is used to indicate whether the CPU wishes to read from a memory location or write to a memory location.

Read Operations
- retrieve a byte of data from memory at the location specified and place it on the data bus. CPU reads the data and places it in one of its internal registers.

Write Operations
- put data from CPU on the data bus and store it in the location specified.

Control Devices
- are outputs, or actuators, that can affect the world around themwhen supplied with a voltage or current.

Monitoring Devices
- are inputs, or sensors, that are stimulated by temperature,pressure, light, motion, etc. and convert this to voltage or current read by the computer.
Note: The interface circuitry converts the voltage or current to binary data, or vice versa.

Memory

A computer memory is of two types; (1). Primary Memory - Internal storage; (2), Secondary Memory - External storage

Primary Memory
This is the internal memory and is the main area in a computer where the data is stored. Stored data can be recalled instantly, quicklyaccessed and correctly whenever desiredby the CPU for reading or storing. Primary memory is classified into two types:Random Access Memory **(RAM) and** Read- Only Memory **(ROM).**

Random Access Memory (RAM)
RAM is also called the read/write memory because information can be read from and written onto it. It is holds instructions for the computer, its programs and the data and the CPU can directly access the data from RAM almost immediately. The storage of data and instructions in RAM is temporary as long as the computer is running but it disappears from RAM as soon as power to the computer is switched off. It is therefore a volatile memory.

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Read- Only Memory (ROM)

It is called Read-only memory. Information can only be read from it and cannot be written or changed onto ROM. The storage of data and instructions in ROM is permanent. It is a'built-in' memory of a computer and stores some **B**asic **I**nput – **O**utput **I**nstructions (**BIOS**) put by the manufacturer to operate the computer. Read Only Memories (ROMs) were the first types of non-volatile semiconductor memories. If you want to use ROMs, you have to hand the data over to the chip manufacturer, where a specific chip is made containing your data.

Mask-ROM - (MROM).

An MROM iscomposed of several layers. The geometrical layout of those layers defines the chip's function. A MROM contains a matrix of memory cells. The name Mask-ROM is derived from the one mask which defines the row-column connections.

Programmable Read Only Memory (PROM)

Programmable Read Only Memory (PROM) is a matrix of memory cells, each containing a silicon fuse. Each fuse is intact and each cell reads as a logical 1. By selecting a cell and applying a high current pulse, the cell's fuse can be destroyed, thereby programming a logical **0** into the selected cell.

Erasable Programmable Read Only Memory (EPROM)

EPROMprogramming is non-destructive and memory is stored in so-called field effect transistors (FETs) or rather in one of their pins called gate. This gate is namedas the floating gate as it is completely insulated from the rest of the circuit. By applying an appropriately high voltage, it is possible to charge the floating gate through a physical process called avalanche injection. Once a cell is programmed, the electrons remain in the floating gate indefinitely. EPROMs are used as PROMs and thus So-called One Time Programmable EPROMs (OTP-EPROMs). The OTP-EPROM is used for mass production.

Electrically Erasable and Programmable ROM (EEPROM)

EEPROM has the advantages of an EPROM without the hassle. No special voltage is required for programming anymore, and – as the name implies – no more UV light source is needed for erasing. EEPROM works very similar to EPROM, except that the electrons can be removed from the floating gate by applying an elevated voltage.EEPROMs endure a limited number of write/erase cycles only (usually in the order of 100.000 cycles) and they do not retain their information indefinitely though they are used regularly in microcontroller applications. It is rather expensive

Flash Memory

Flash is a variant of EEPROM where erasing is not possible for each address, but only for larger blocks or even the entire memory.Its internal logic is simplified, which in turn reduces the price considerably. Flash EEPROM is used for program and not data memory.Flash-EEPROMs have a

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lower guaranteed write/erase cycle endurance compared to EEPROMs – about 1,000 to 10,000 cycles. Flash-EEPROMs are cheaper.

Non-Volatile RAM - (NVRAM)

This is a type of memory that combines the advantages of volatile and non-volatile memories andis achieved by add a small internal battery to an SRAM device so that when external power is switched off to retain power so that the SRAM still retains its content or bycombining a SRAM with an EEPROM in one package. Upon power-up, data is copied from the EEPROM to the SRAM. During operation, data is read from and written to the SRAM. When power is cut off, the data is copied to the EEPROM.

Accessing Memory

Many microcontrollers come with on-chip program and data memory with two methods of accessing memory:

i. Each memory is addressed separately. In ATmega16, the address ranges has three different memory types. The programmer specifies which memory is to be accessed by using different access methods.
ii. All memory types share a common address range. In HCS12 the programmer accesses EEPROM in the same way as SRAM. The microcontroller uses the address to decide which memory the access goes to.

Suppose a 16 bit controller writes a word (two bytes) into SRAM, say at address 0x0100. The word consists of a low and a high byte. There are two variants: the low byte could go to 0x0100 and the high byte to the next address (0x0101), or the other way around. That is the problem ofendianness:

Big Endian:

Big Endian architectures store the high byte first. So, if you write the word 0x1234 to address 0x0100, the high byte 0x12 goes to address 0x0100, and the low byte 0x34 to address 0x0101. The name is derived from this order: The Big End of the word is stored first – therefore, it is called Big Endian.

Little Endian:

Little Endian architectures access memory the other way around i.e. Little End of the word first. The low byte is stored first. Writing 0x1234 at address 0x0100 on a little endian architecture writes 0x34 to address 0x0100 and 0x12 to address 0x0101.

Input/Output Ports

The 8051 microcontrollers has four I/O ports each of 8 bits which is configured as inputs or outputs. A total of 32 input/output pins enable the microcontroller to be connected to peripheral devices. Pin configuration, **i.e.** whether it is to be configured as an input (1) or an output (0) depends on its logic state. In order to configure a microcontroller pin as an output, you apply logic zero (**0**) to appropriate I/O port bit. Voltage level on appropriate pin will be **0**. In order to

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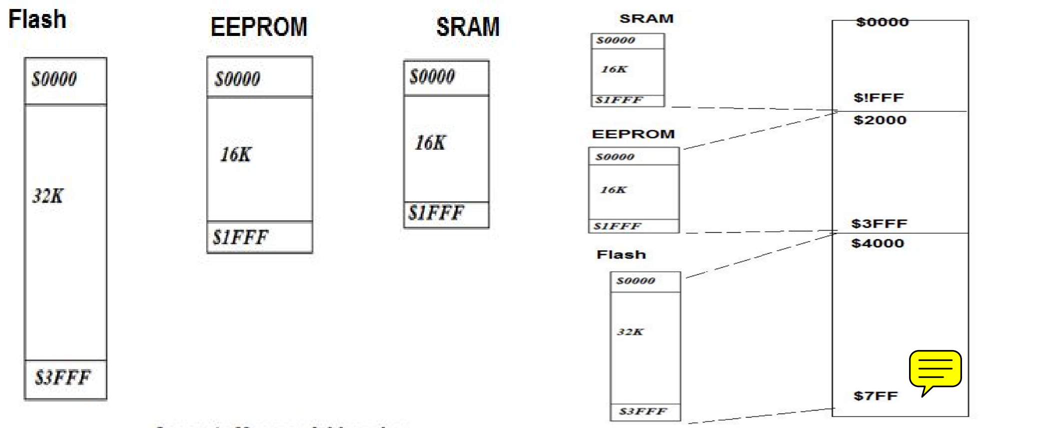
configure a microcontroller pin as an input, apply a logic one (**1**) to appropriate port and the voltage level on appropriate pin will be 5V.

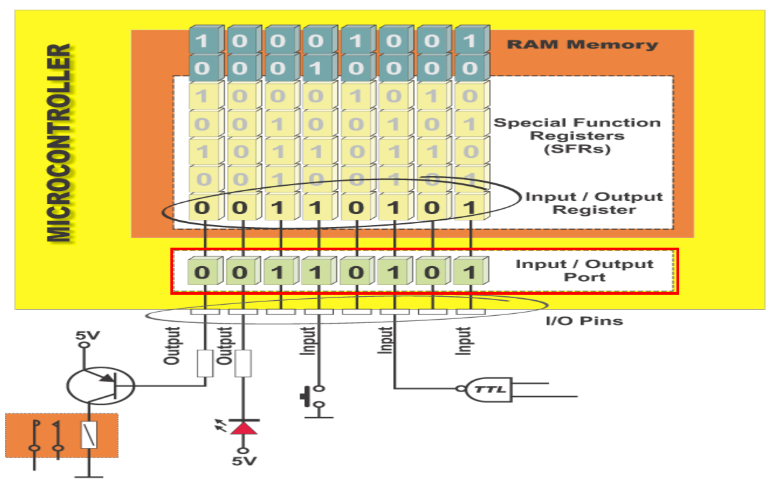
Timers

Timers are used for a variety of tasks ranging from simple delays over measurement of periods to waveform generation. The timer module is a counter module and controllers provide one or more timers with 8 and/or 16 bit resolution. The use of the timer is as a counter. Timers allow the user to time-stamp external events, to trigger interrupts after a certain number of clock cycles, and to generate pulse-width modulated signals for motor control.



Separate Memory Addressing.

Different memory types mapped into one address range



Counters

Each timer is a counter which is either incremented or decremented upon every clock tick. The direction is either fixed or configurable. The current count value can be read through a count register and can be set to a specific value by the user. For a timer resolution of n, the count value is within [0, 2^{n-1}]. Timers raise an interrupt whenever they experience an overflow of the count value.This can be used to implement a rudimentary periodic signal by setting the count value to a givenstart value and then waiting for the overflow.

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System Clock (orInternal Clock)
In this mode, the timer is incremented with every tick of the system clock. This is the default mode. Note that the term "internal" only refers to the fact that this is the clocking source the whole controller uses. The oscillator responsible for it may well be external.

Prescaler
This mode also uses the system clock but filtered through a prescaler. The prescaler is another counter of variable length of 8 or 10 bit are values which is incremented with the system clock. The timer itself, however, is clocked by one of the prescaler bits. The bit next to the*lsb* will again divide the frequency by two, and so on. The timer module provides mode bits which allow the user to select some prescale values (8, 64, 256, . . .).

TOPIC THREE
MICROCONTROLLER FAMILIES

Microcontrollerfamilies are classified into series. These include the following types of series:

A). Intel 8048 microcontroller Series
This type of microcontrollers has the following features;
Memory

Has Data memory and stack memory occupy the same memory space while Program memory is separate from data and stack memory.

Program memory

It consists of 1 KB on-chip masked ROM and up to 3 KB of external program memory. It is possible to disable on-chip memory and use up to 4 KB of external memory. The total size of supported program memory is 4 KB. Conditional branch and unconditional indirect jump instructions is used to jump program memory. Unconditional jump and call instructions are used to address within current 2 KB program memory block.

Data memory–

It consists of 64 bytes of on-chip RAM and up to 256 bytes of external RAM where;

i. 16 bytes of on-chip RAM are used for 2 banks of working registers, located at addresses 00h - 07h (bank 0) and 18h - 1Fh.
ii. Up to 16 bytes of on-chip RAM at addresses 08h - 17h are used as stack memory.
iii. The rest of the on-chip RAM can be accessed indirectly.
iv. Up to 256 bytes of external memory can be accessed using MOVX instruction.

Stack is stored in data memory locations 08h - 17h (8 - 23) and can be 8-levels deep. The stack starts at location 08h and grows upwards and when a CALL instruction is executed the return

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address (12 bits) and the upper 4 bits of the program status word (CY, AC, F0 and BS flags) are stored in the stack.

Reserved locations include:

- 0000h - the MCU starts executing instructions at this address after RESET.
- 0003h - the MCU jumps to this address when an external interrupt occurs.
- 0007h - the MCU jumps to this address when a timer/counter interrupt occurs.

Interrupts

The processor has two maskableinterrupts which are:

i. **INT external interrupt**

When this interrupt occurs, the microcontroller disables any further interrupts, saves the program counter and part of the program status word into stack, and jumps to address 0003h. This address usually contains a jump instruction to interrupt processing routine. To return from the interrupt the routine should use RETR instruction.

ii. **Timer/counter interrupt**

This interrupt occurs when the counter overflows, i.e. when it has the value FFh and it's incremented. When the interrupt occurs the microcontroller disables further interrupts, saves the program counter and part of the program status word into stack, and jumps to address 0007h. This address usually contains a jump instruction to interrupt processing routine.

I/O ports

It has twenty sevenI/O lines:

- 8-bit quasi-bidirectional ports 1 and 2.
- 8-bit bidirectional BUS port.
- 3 Test inputs

Registers

Program counter

It is a 12 bit most significant bit of the program counter is not updated when the program counter is incremented. To tell the MCU to set/reset this bit the program should use SEL MB1 or SEL MB0 instructions.

Accumulatoris used for data moving, arithmetic, logic and I/O operations.

Workingregistersare used for temporary data storage. These registers can be addressed directly by many instructions. There are two sets of working registers - bank 0 and bank 1, each bank has 8 working registers.

RAM pointer registersare used by many instructions to address RAM indirectly. These registers are located in RAM. Their addresses are 00h and 01h for register bank 0, and 18h and 19h for register bank 1.

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Program status word consists of the following bits:

- Carry (CY) - set to 1 if there is a carry from the MSB during last ADD operation.
- Auxiliary carry (AC) - set by last ADD instruction.
- Flag 0 (F0) - user flag. This flag can be set/reset by user program, and can be tested using JF0 instruction. The MCU also has flag 1 that can be set/reset/tested similar to flag 0, but the flag 1 is not a part of program status word register.
- Register bank select (BS) - set to 0 to use the bank 0 (RAM locations 00h - 07h), set to 1 for the bank 1 (RAM locations 18h - 1Fh).

Instruction Set

8048 instruction set consists of the following instructions:

- Data moving instructions.
- Arithmetic - add, increment and decrement. No subtract nor compare instructions.
- Logic - rotate, AND, OR, exclusive OR, NOT and bit test.
- Control transfer - conditional branch (limited to current 256-byte page) and unconditional jumps and calls (limited to current 2 KB memory block).
- Input/Output instructions - input, output and logic operations with port data.
- Timer/counter related instructions - start, stop and read value of the timer/counter.
- Other - flag operations, decimal adjust, nibble swap, memory bank selection, enable/disable interrupts, etc.

Addressing Modes

i. **Implied addressing** - the data value/data address is implicitly associated with the instruction.

Accumulator - the instruction implies that the accumulator contains data.

Register - references data in one of 8 working registers in the currently selected data memory bank.

ii. **Immediateaddressing**- 8-bit data is provided in the instruction.

iii. **Absoluteaddressing**- the instruction operand specifies the memory address where control is transferred. The instruction may have 8-bit or 11-bit operand:

- 8-bit operands are used to transfer control within current 256-byte program memory page.
- 11-bit operands are used to transfer control within current 2 KB program memory block.

iv. **Register indirectaddressing–** instruction specifies RAM pointer register that contains RAM address, where data is located.

Accumulator indirect– the accumulator contains a program memory address within current 256-byte program memory page where the program control will be transferred.

B).Intel 8051 Microcontroller

The 8051 family having the IC diagram and its internal block diagram showing I/O, PC, RAM, CPU, Timers and Interrupts. Intel 8051 microcontroller has; 4 Kb of ROM; 128b of RAM that

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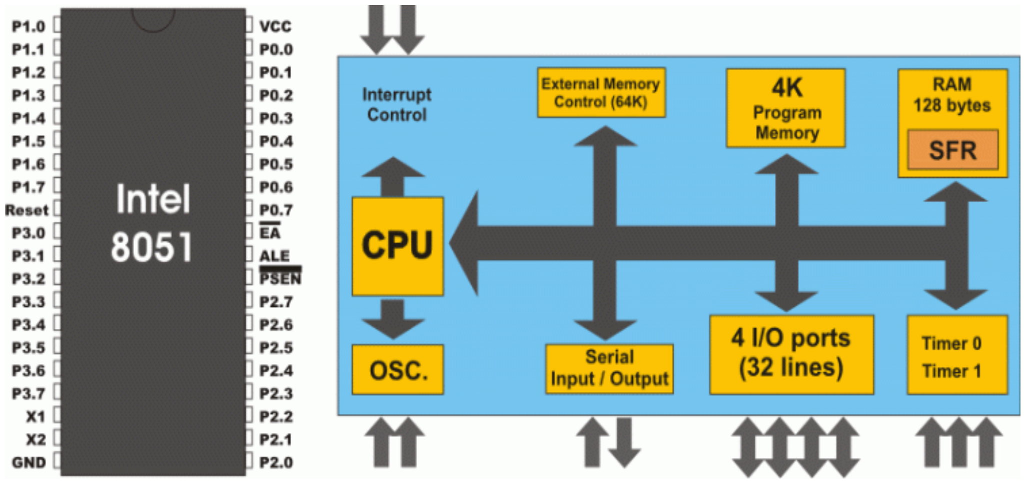
satisfies the user's basic needs and 4 ports having in total of 32 input/output lines. Its RAM is organized, the operation of Central Processor Unit (CPU) and ports enable further upgrade.



Pin-out Description

Pins 1-8: Port 1- Each of these pins can be configured as an input or an output.

Pin 9: RS-A logic one on pin 9 disables the microcontroller and clears the contents of registers. A logic zero to pin 9 the program starts execution from the beginning.

Pins10-17: Port 3- Similar to port 1, each of these pins can serve as general input or output.

Pin 10: RXD- Serial asynchronous input /synchronous communication output pin.

Pin 11: TXD-Serial asynchronous c output /Serial synchronous communication clock output.

Pin 12: INT0- Is the Interrupt 0 input.

Pin 13: INT1- is the Interrupt 1 input.

Pin 14: T0- is the Counter 0 clock input.

Pin 15: T1- is the Counter 1 clock input.

Pin 16: WR- is the Write to external (additional) RAM.

Pin 17:- RD- is the Read from external RAM.

Pin 18, 19: X2, X1-is the internal oscillator input and output. A quartz crystal which specifies operating frequency is connected to these pins.

Pin 20: GND- is the Ground terminal.

Pin 21-28: Port 2- If there is no intention to use external memory then these port pins are configured as general inputs/outputs. The higher address byte, i.e. addresses A_8-A_{15} will appear on this port.

Pin 29: PSEN- If external ROM is used for storing program then a logic zero (0) appears on it every time the microcontroller reads a byte from memory.

Pin 30: ALE- Prior to reading from external memory, the microcontroller puts the lower address byte (A_0-A_7) on P_0 and activates the ALE output. After receiving signal from the ALE pin, the external register memorizes the state of P0 and uses it as a memory chip address.

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Pin 31: EA- By applying logic zero to this pin, P2 and P3 are used for data and address transmission with no regard to whether there is internal memory or not. It means that even there is a program written to the microcontroller, it will not be executed.

Pin 32-39: Port 0- Similar to P2, if external memory is not used, these pins are used as general inputs/outputs. Otherwise, P0 is configured as address output (A0-A7) when the ALE pin is driven high (1) or as data output (Data Bus) when the ALE pin is driven low (0).

Pin 40: VCC- is the +5V power supply source pin.

Input/Output (I/O) pin

- **Output pin**

A logic zero (**0**) is applied to a bit of the P register. The output FE transistor is turned on, thus connecting the appropriate pin to ground.

- **Input pin**

A logic one (**1**) is applied to a bit of the P register and the output FE transistor is turned off and the appropriate pin remains connected to the power supply voltage over a pull-up resistor of high resistance.

Input/Output Ports (I/O Ports)

Microcontrollers have 4 I/O ports each comprising 8 bits which can be configured as inputs or outputs. In total of 32 input/output pins enabling the microcontroller to be connected to peripheral devices are available for use. Pin configuration, i.e. whether it is to be configured as an input (1) or an output (0), depends on its logic state. In order to configure a microcontroller pin as an output, it is necessary to apply a logic zero (0) to appropriate I/O port bit.

Port 0

The P0 port is characterized by two functions. If external memory is used then the lower address byte (addresses A_0-A_7) is applied on it. All bits of this port are configured as inputs/outputs.. When the pin is configured as an output, it acts as an “open drain”.

Port 1

P1 is a true I/O port, because it doesn't have any alternative functions as is the case with P0, but can be configured as general I/O only.

Port 2

P2 acts similarly to P0 when external memory is used. Pins of this port occupy addresses intended for external memory chip.

Port 3

All port pins can be used as general I/O, but they also have an alternative function. In order to use these alternative functions, a logic one (1) must be applied to appropriate bit of the P3 register.

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Memory Organization in 8051 Microcontrollers

Intel 8051 has two types of memory. Program Memory (ROM) is used to permanently save the program being executed, while Data Memory (RAM) is used for temporarily storing data and intermediate results created and used during the operation of the microcontroller. 8051 microcontrollers have a 16-bit addressing bus and are capable of addressing 64 kb memory.

i. Program Memory

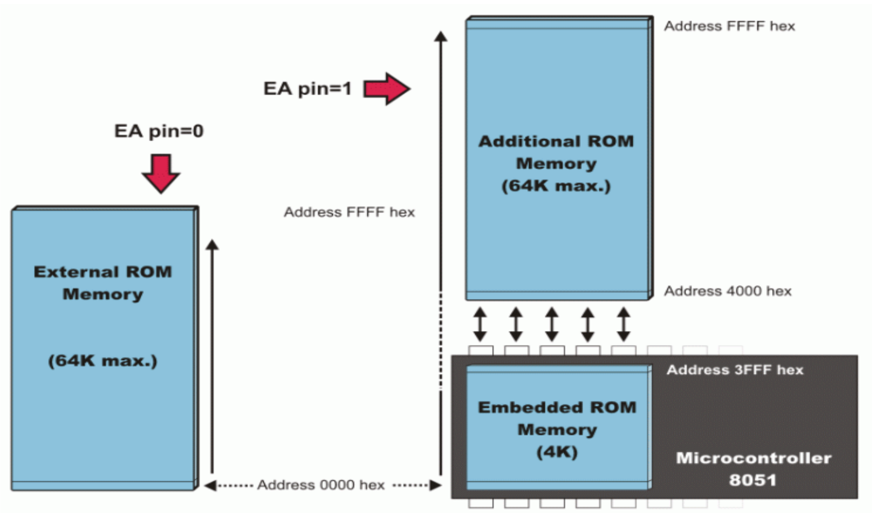
All models have a few Kbyte ROM embedded though a memory is sufficient for writing most of the programs.How it handles external memory depends on the EA pin logic state:

EA= 0 -; the microcontroller ignores internal program memory and executes only the program stored in external memory.

EA = 1; the microcontroller executes first the program from built-in ROM and then the program stored in external memory.

ii. Data Memory

Data Memory is used to store data temporarily and RAM in 8051 family has many registers such as hardware counters and timers, input/output ports, serial data buffers etc. The first block consists of 4 banks each including 8 registers denoted by R0-R7. The next memory block (address 20h-2Fh) is bit- addressable which means that each bit has its own address (0-7Fh). Since there are 16 such registers, this block contains in total of 128 bits with separate addresses. The third group of registers occupies addresses 2Fh-7Fh.



Memory expansion

It is possible to add two external memory chips with capacity of 64Kb each. P2 and P3 I/O ports are used for their addressing and data transmission. The first one is used for reading data from external data memory (RAM) while the other is used for reading data from external program memory (ROM).

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Addressing modes in 8051 microcontrollers

There are two ways of addressing are used for all 8051 microcontrollers depending on which part of memory should be accessed:

i. Direct Addressing

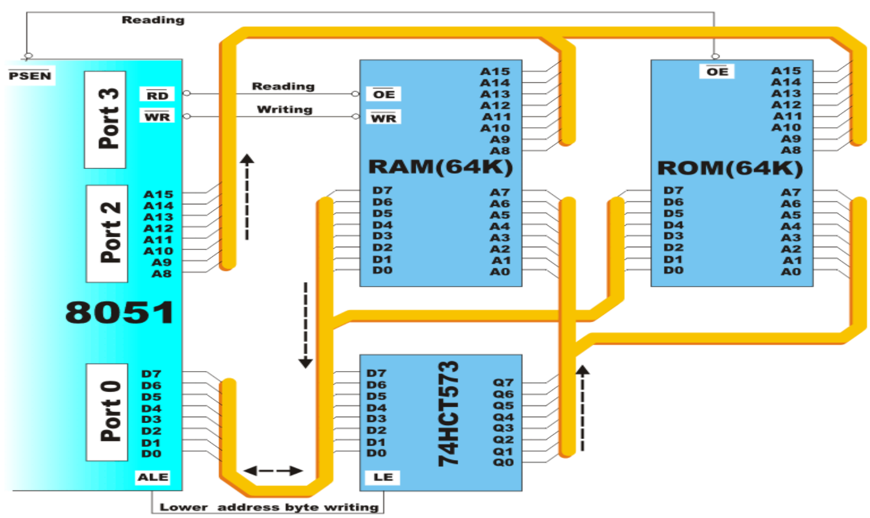
The address of memory location containing data to be read is specified in an instruction. The address may contain a number being changed during operation (variable). Since the address is only one byte in size (the largest number is 255), only the first 255 locations of RAM can be accessed this way. The first half of RAM is available while another half is reserved for SFRs.

MOV A, 33h; Means: move a number from address 33 hex. to accumulator

ii. Indirect Addressing

A register containing the address of another register is specified in instruction. Data to be used in the program is stored in the letter register. Indirect addressing is only used for accessing RAM locations available for use (never for accessing SFRs). When the program encounters instruction including "( )" sign and if the specified address is higher than 128 (7F hex.), the processor knows that indirect addressing is used and skips memory space reserved for SFRs.

MOV A, (R0); Means: Store the value from the register whose address is in the R0 register into accumulator



Special Function Registers (SFRs)

These are used for running and monitoring the operation of the microcontroller. Each of these registers include has its name, address in the scope of RAM and a defined purpose such as timer control, interrupt control, serial communication control etc.

The A Register (Accumulator)

Prior to executing an instruction upon any number or operand it is necessary to store it in the accumulator first. All results obtained from arithmetical operations performed by the ALU are

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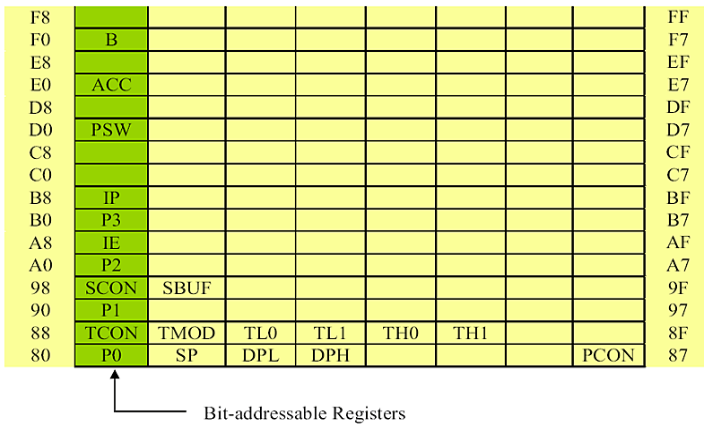
stored in the accumulator. Data to be moved from one register to another must go through the accumulator.

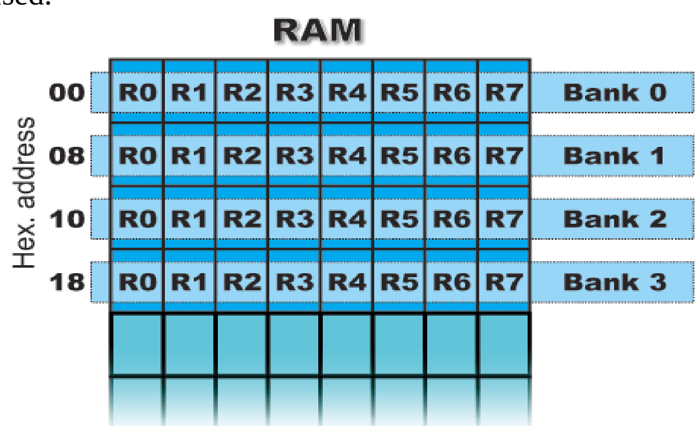
The B Register

Multiplication and division can be performed only upon numbers stored in A and B registers.



The R Registers (R0-R7)

This is a name for 8 general-purpose registers (R0, R1, R2 ...R7). They occupy 4 banks within RAM and are used for temporary storing variables and intermediate results during operation. The active banks depend on two bits of the PSW Register. Active bank is a bank the registers of which are currently used.



Suppose it is necessary to perform some arithmetical operations upon numbers previously stored in the R registers: (R1+R2) - (R3+R4). A register for temporary storing results of addition is needed. This is how it looks in the program:

MOV A,R3; Means: move number from R3 into accumulator
ADD A,R4; Means: add number from R4 to accumulator (result remains in accumulator)
MOV R5,A; Means: temporarily move the result from accumulator into R5
MOV A,R1; Means: move number from R1 to accumulator
ADD A,R2; Means: add number from R2 to accumulator
SUBB A,R5; Means: subtract number from R5 (there are R3+R4)

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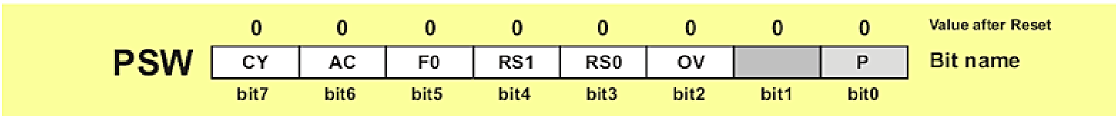
Program Status Word (PSW) Register

PSW register contains several status bits that reflect the current state of the CPU. This register also contains Carry bit, Auxiliary Carry, two register bank select bits, Overflow flag, parity bit and user-definable status flag.



P - Parity bit- if a number stored in the accumulator is even then this bit will be automatically set (**1**), otherwise it will be cleared (**0**). It is mainly used during data transmit and receive via serial communication.

- Bit 1. This bit is intended to be used in the future versions of microcontrollers.

OV Overflow- occurs when the result of an arithmetical operation is larger than 255 and cannot be stored in one register. Overflow condition causes the OV bit to be set (**1**). Otherwise, it will be cleared (**0**).

RS0, RS1 - Register bank select bits. These two bits are used to select one of four register banks of RAM. By setting and clearing these bits, registers R0-R7 are stored in one of four banks of RAM.

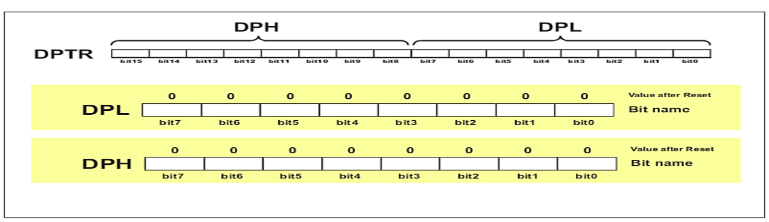
F0 - Flag 0. This is a general-purpose bit available for use.

AC - Auxiliary Carry Flagis used for BCD operations only.

CY - Carry Flag is the (ninth) auxiliary bit used for all arithmetical operations and shift instructions.

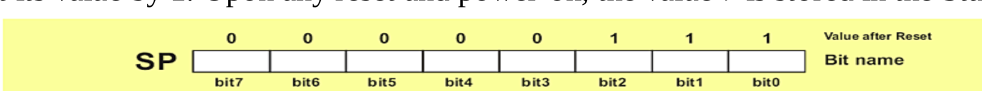
Data Pointer Register (DPTR)

It consists of two separate registers which is{DPH (Data Pointer High) and (Data Pointer Low)}. For this reason it may be treated as a 16-bit register or as two independent 8-bit registers. Their 16 bits are primarily used for external memory addressing. The DPTR Register is used for storing data and intermediate results.



Stack Pointer (SP) Register

A value stored in the Stack Pointer points to the first free stack address and permits stack availability. Stack pushes increment the value in the Stack Pointer by 1. Likewise, stack pops decrement its value by 1. Upon any reset and power-on, the value 7 is stored in the Stack Pointer.



P0, P1, P2, P3 - Input/Output Registers

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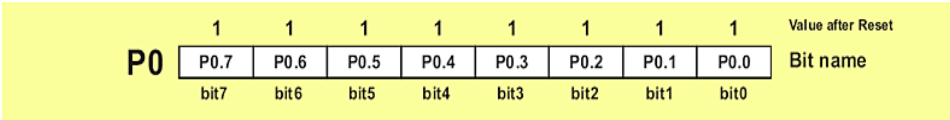
If neither external memory nor serial communication system are used then 4 ports within total of 32 input/output pins are available for connection to peripheral environment. Each bit within these ports affects the state and performance of appropriate pin of the microcontroller.



Counters and Timers

The 8051 microcontroller has 2 timers/counters called T0 and T1. Their main purpose is to measure time and count external events and also for generating clock pulses to be used in serial communication, so called Baud Rate. If the timer is properly programmed, the value stored in its register will be incremented (or decremented) with each coming pulse, i.e. once per each machine cycle.

Universal Asynchronous Receiver and Transmitter (UART)

An integrated UART, better known as a serial port is a full-duplex port, thus being able to transmit and receive data simultaneously and at different baud rates. Without it, serial data send and receive would be an enormously complicated part of the program in which the pin state is constantly changed and checked at regular intervals. When using UART, all the programmer has to do is to simply select serial port mode and baud rate. When it is done, the serial data transmit by writing to the SBUF register while data receive represents reading the same register. The microcontroller takes care of not making any error during data transmission. Serial port must be configured prior to being used to determine how many bits is contained in one serial “word”, baud rate and synchronization clock source. The whole process is in control of the bits of the SCON register.

TRANSMIT - Data transmission is initiated by writing data to the SBUF register. This process starts after any instruction being performed upon this register. When all 8 bits have been sent, the TI bit of the SCON register is automatically set.

RECEIVE - Data receive through the RXD pin starts upon the two following conditions are met: bit REN=1 and RI=0 (both of them are stored in the SCON register). When all 8 bits have been received, the RI bit of the SCON register is automatically set indicating that one byte receives is complete.

Intel 8051 Microcontroller Interrupts

There are five interrupt sources for the 8051, which means that they can recognize 5 different events that can interrupt regular program execution. Each interrupt can be enabled or disabled by setting bits of the IE register. The whole interrupt system can be disabled by clearing the EA bit of the same register.

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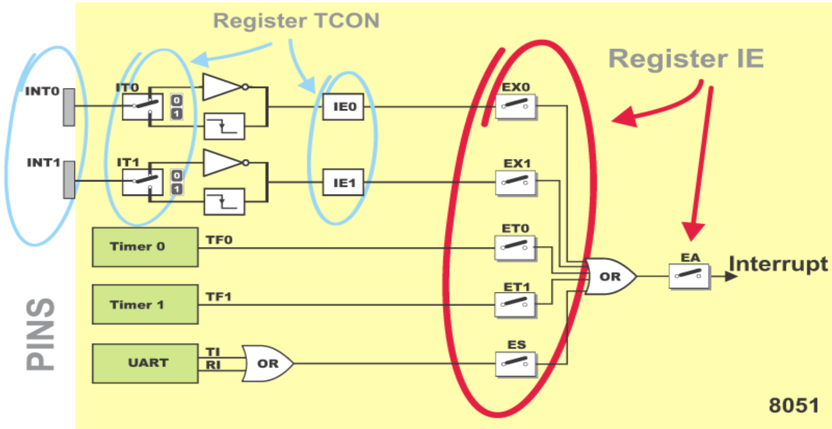
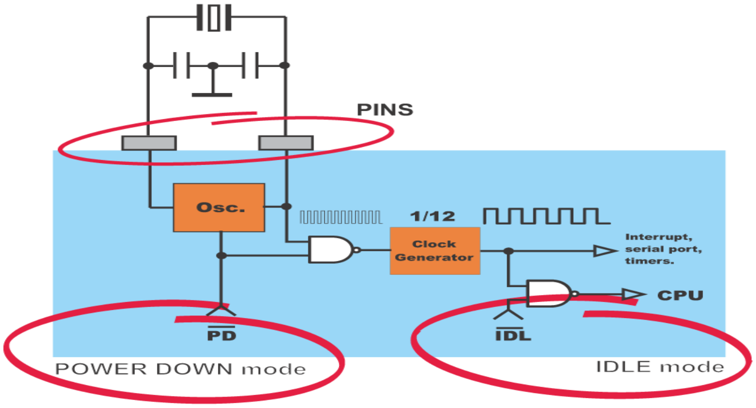


Intel 8051 Microcontroller Power Consumption Control

A microcontroller is inactive for the most part and just waits for some external signal in order to takes its role in a show. In extreme cases, the only solution is to set the whole electronics in sleep mode in order to minimize consumption. A typical example is a TV remote controller: it can be out of use for months but when used again it takes less than a second to send a command to TV receiver. Actually, there are two power-saving modes of operation: *Idle* and *Power Down.*



ASSIGNMENT

Discuss the following microcontrollers

i). Intel 8096,

ii). NEC 7800

iii). Intel 8044

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TOPIC TWO
PROCESS CONTROL SYSTEMS

Process control is a sustained phenomenon or one marked by gradual changes through a series of states.The paramount needs ofsystem process control are;

i. **Safety**

   The state of being certain that adverse effects will not be caused by some agent under defined conditions and nobody will be affected or inconvenienced in the process.

ii. **Quality**

   a characteristic property that defines the apparent individual nature of something toensure that a property generated is of high and precise required level.

iii. **Environment**

   The totality of surrounding conditions must be maintained and controlled so as not to affect life and quality of product is maintained.

iv. **Economics**

   This deals with the production and distribution and consumption of goods and services and their management. Production of products and services are of fair price.

System Process Control terms

i. **Lag time**

   Lag time is the amount of time after the dead time that the process variable takes to move 63.3% of its final value after a step change in valve position.

ii. **Dead time**

   Dead time is the amount of time it takes for the process variable to start changing after changing output as a control valve, variable frequency drive etc.

iii. **Dead band**

iv. A region selected around the set-point where proportional control is withheld. This is usually between the heating and cooling proportional bands.Deadband is a range of values near the set point within which the controller will not change its mode. In the example described above a deadband of 1F° (from 79.5 to 81.5°F) may be set. Now the controller will not open the steam valve until the product temperature falls below 79.5°F and will not close the steam valve until the product temperature rises above 80.5°F.

v. **Set point**

   The set point is the desired value of the process variable. **Set Point** can also be defined as the value of the controlled variable (e.g., 80°F) at which the control action takes place (e.g., steam valve opens/closes).

vi. **Error signal**

   In the control loop the error = set point - process value

vii. **Transient**

   A short-lived oscillation or signal in a system caused by a sudden change of voltage or current or load.

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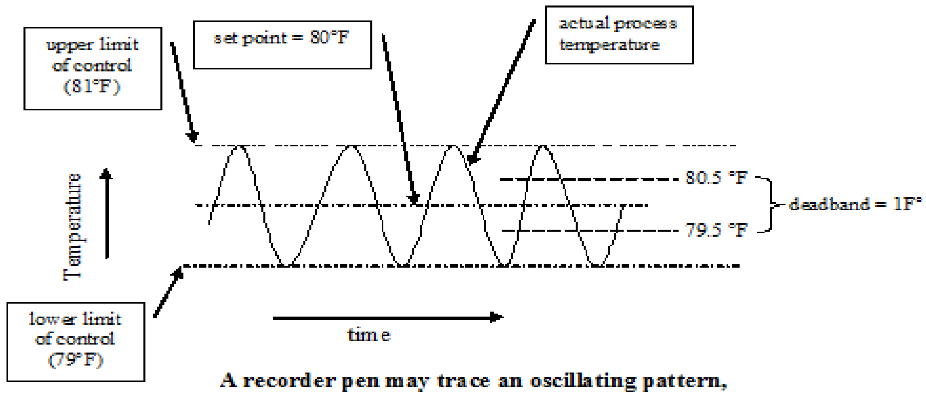


A recorder pen may trace an oscillating pattern, the upper and lower values of which are the limits of control.

viii. **Measured variable**

ix. **Controlled variable**

x. **Variable range**

Range is from the lowest to the highest values controlled.

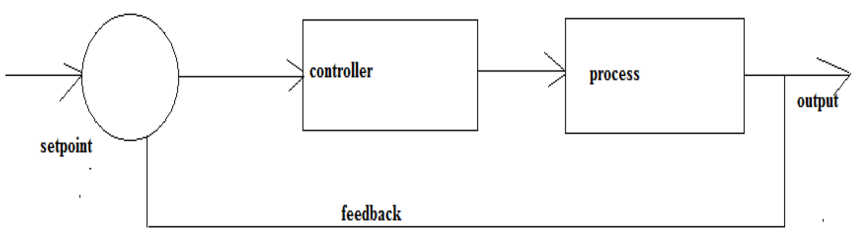
xi. **Control parameter range**

xii. **Offsetor"droop."**

-difference in temperature between set-point and actual process temperatures

Block Diagram of process control

It contains the set-point, controller, process , feedback and output as shown below.



This is a process control system

Control modes

Controllers use3 basic modes: P - proportional, I - integrative and D - derivative.Combinations such as PI and PD control are very often in practical systems. The control modeincludes the following:

a. The ON/OFFcontrol mode

An **ON-OFF**controller makes the device to be either **ON** or **OFF** with no middle state. It will switch the output only when the temperature crosses the set-point. The **ON/OFF** allows only 2 control valve positions; fully opened or fully closed.When the process water temperature is less than the set point of 80 °C, the steam valve opens fully and when the process water reaches or

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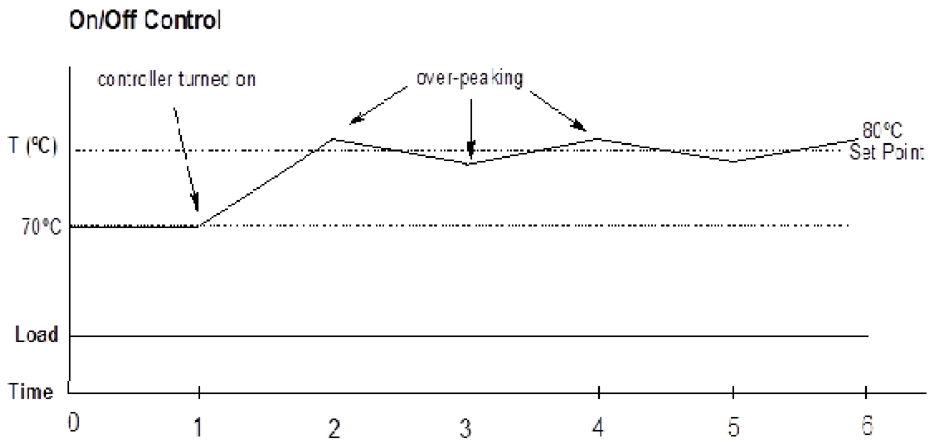
exceeds 80 ºC, the controller signals the control valve to close fully. It is the least expensive equipment and is suitable when there is a large capacityprocess.



For heating control, the output is on when the temperature is below the set-point, and off above set-point. Since the temperature crosses the set-point to change the output state, the process temperature will be cycling continually, going from below set-point to above, and back below. One special type of on-off control used for alarm is a limit controller. This controller uses a latching relay, which must be manually reset and is used to shut down a process when a certain temperature is reached.

b. Proportional control mode

Proportional controls are designed to eliminate the cycling associated with on-off control. A proportional controller decreases the average power supplied to the heater as the temperature approaches set-point. This has the effect of slowing down the heater so that it will not overshoot the set-point, but will approach the set-point and maintain a stable temperature. This proportioning action can be accomplished by turning the output on and off for short intervals. This "time proportioning" varies the ratio of "on" time to "off" time to control the temperature. The proportioning action occurs within a "proportional band" around the set-point temperature. Outside this band, the controller functions as an on-off unit, with the output either fully on (below the band) or fully off (above the band). Within the band, the output is turned on and off in the ratio of the measurement difference from the set-point. At the set-point (the midpoint of the proportional band), the output ON:OFF ratio is 1:1; that is, the on-time and off-time are equal. if the temperature is further from the set-point, the on- and off-times vary in proportion to the temperature difference. If the temperature is below set-point, the output will be on longer; if the temperature is too high, the output will be off longer. P controller cannot stabilize higher order processes. For the 1^{st} order processes, meaning the processes with one energy storage, a large increase in gain can be tolerated. Proportional controller can stabilize only 1st order unstable process. Changing controller gain K can change closed loop dynamics. A large controller gain will result in control system with:

a) smaller steady state error, i.e. better reference following

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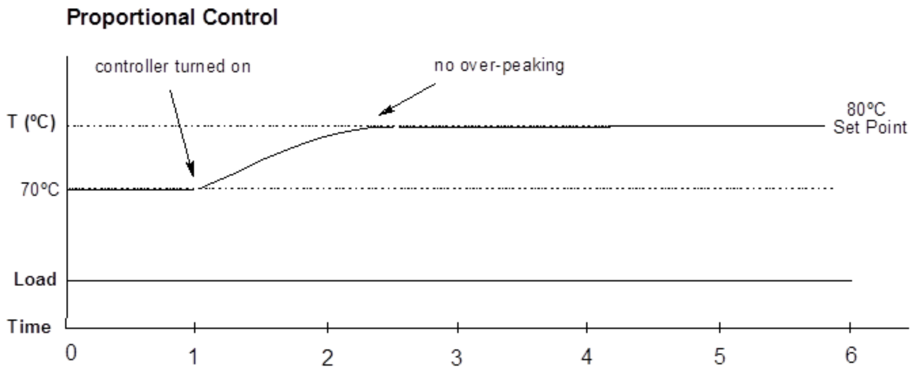
b) faster dynamics, i.e. broader signal frequency band of the closed loop system and larger sensitivity with respect to measuring noise

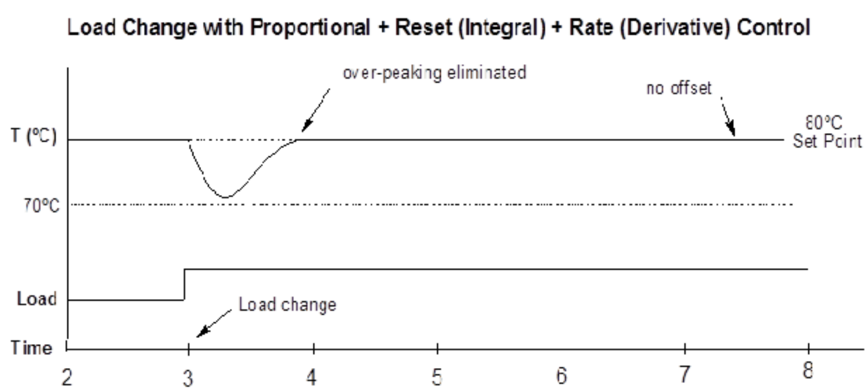
c) smaller amplitude and phase margin

When P controller is used, large gain is needed to improve steady state error. Stable systems do not have problems when large gain is used. If constant steady state error can be accepted with such processes, than P controller can be used. Small steady state errors can be accepted if sensor will give measured value with error or if importance of measured value is not too great anyway.



c. Derivative control mode

Derivative (Rate) control responds to the rate of change of the measured variable. In case of a sudden and large process load change, the rate control adds a signal to the control valve, increasing the controller's output signal in addition to the proportional and integral signals. However, as the rate of change of the measured variable slows down, the derivative signal reduces and the valve opening is decreased to the position called for by the proportional and integral signals only. The result is that the integral signal has not had time to grow excessively large but is closer to a level appropriate to the new process load. Over-peaking is significantly reduced. Derivative control is not suitable for noisy process signals since the rapid rate of change of the measured variable will cause the controller to overreact by widely opening and closing the control valve which in turn causes process instability.



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d. Integral control mode

Adding an Integral (Reset) Mode causes the controller to open the steam valve further when an error is measured by sending an output signal in addition to the proportional mode signal. As long as a negative offset remains, the integral mode continues to open the valve wider and wider until no error is detected. The integral signal remains constant after the process temperature reaches the set point and resets the controller so that the proportional signal returns to the same output level it produced before the load change. When a large process load change occurs a large "process lag" may result.**Process lag** is the delay time it takes the controlled variable (water) to respond to a change in the controller output signal. In such a case, the error signal persists for some time before the process can return to the set point and this may cause the control valve to open too wide.

e. Proportional +integral (PI)

PI controller eliminates forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. Since a PI controller does not have a mean to predict what will happen with the error in near future,it is solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller. PI controllers are used in industry. The control mode is used when:

a) fast response of the system is not required
b) large disturbances and noise are present during operation of the process
c) there is only one energy storage in process (capacitive or inductive)
d) there are large transport delays in the system

f. Proportional + Differential (PD)

PD mode is used when prediction of the error can improve control or when it necessary to stabilize the system. From the frequency characteristic of D element it can be seen that it has phase lead of 90°. Sudden change in error signal will cause sudden change in control output. To avoid that it is suitable to design D mode to be proportional to the change of the output variable. PD controller is often used in control of moving objects such are flying and underwater vehicles, ships, rockets etc. because stabilizing effect of PD controller on sudden changes in heading variable is easy.

g. Proportional + Integral + Differential (PID)

The type of controller provides a *proportional with integral and derivative control* andcombines proportional control with two additional adjustments that helps the unit to automatically compensate for changes in the system. These adjustments, integral and derivative, are expressed in time-based units; they are also referred to as RESET and RATE respectively. The proportional, integral and derivative terms must be individually adjusted or "tuned" to a particular system using trial and error. It provides the most accurate and stable control of the three controller types and is best used in systems which have a relatively small mass, those which react quickly to changes in the energy added to the process. It is recommended in systems

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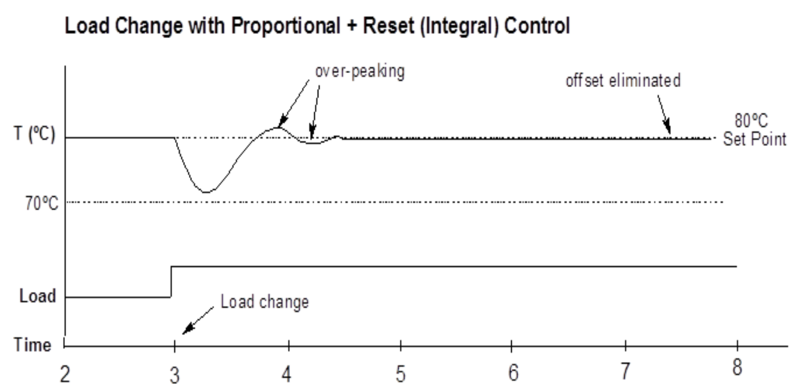
where the load changes often and the controller is expected to compensate automatically due to frequent changes in set-point, the amount of energy available, or the mass to be controlled.Because of features that include auto- or self-tuning, where the instrument will automatically calculate the proper proportional band, rate and reset values for precise control; serial communications, where the unit can "talk" to a host computer for data storage, analysis, and tuning; alarms, that can be latching (manual reset) or non-latching (automatic reset), set to trigger on high or low process temperatures or if a deviation from set-point is observed; timers/event indicators which can mark elapsed time or the end/beginning of an event.

PID controller has fast reaction on change of the controller input (D mode), increase in control signal to lead error towards zero (I mode) and suitable action inside control error area to eliminate oscillations (P mode). Derivative mode improves stability of the system and enables increase in gain K and decrease in integral time constant Ti, which increases speed of the controller response. PID controller is used when dealing with higher order capacitive processes when their dynamic is not similar to the dynamics of an integrator (like in many thermal processes). Conventional autopilot is for the most part PID type controllers.



PID Tuning Methods

Tuning

This is adjusting control parameters to optimum values for a desired control response. Stability is a basic requirement of tuning since different systems have different behaviors for different applications requirements. PID tuning is a difficult because it must satisfy a complex criterion within limitations of PID control accordingly tuning methods:

i. Manual tuning method,
ii. Ziegler–Nichols tuning method,
iii. PID tuning software methods.

1. **Manual Tuning Method**

Parameters are adjusted by watching system responses. Parameters *Kp, Ki, Kd* are changed until desired or required system response is obtained. Firstly, K_i and K_d are set to zero. Then, the K_p is increased until the output of the loop oscillates, after obtaining optimum K_p value, it should be

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set to approximately half of that value for a "quarter amplitude decay" type response. Then, $K_i$is increased until any offset is corrected in sufficient time for the process. Too much K_i will cause instability. Finally, K_d is increased, until the loop is acceptably quick to reach its reference after a load disturbance.

Parameter	Rise Time	Overshoot	Settling Time	S.S Error	Stability
Kp	Decrease	Increase	Small Change	Decrease	Worse
Ki	Decrease	Increase	Increase	Significant Decrease	Worse
Kd	Minor Dec.	Minor Dec.	Minor Dec.	No change	If Kd small, Better.

2. Tuning of PID-Ziegler-Nichols method

The Ziegler-Nichols' closed loop method is based on experiments executed on an established control loop as follows:

I. Bring the process by manually adjusting the control variable to the specified operating point of the control system to ensure that the controller during the tuning is "feeling" representative process dynamic and to minimize the chance that variables during the tuning reach limits.

II. Turn the PID controller into a P controller by setting set $T_i = \infty$ and $T_d = 0$. Initially, gain K_p is set to "0". Close the control loop by setting the controller in automatic mode.

III. Increase K_p until there are sustained oscillations in the signals in the control system, e.g. in the process measurement, after an excitation of the system. ThisK_p value is denoted the ultimate gain, K_{pu}. The excitation can be a step in the set-point. This step must be small, so that the process is not driven too far away from the operating point where the dynamic properties of the process may be different.

IV. Measure the ultimate period P_u of the sustained oscillations.

V. Calculate the controller parameter values. If the stability of the control loop is poor, stability is improved by decreasing K_p. The table shows the Ziegler–Nichols tuning method, gain parameter's calculation.

Control Type	Kp	Ki	Kd
P	0.5*Ku	-	-
PI	0.45*Ku	1.2*Kp/Tu	-
PID	0.6*Ku	2*Kp/Tu	Kp*Tu/8

3. PID Tuning Software

There are prepared software that they can easily calculate the gain parameter. Any kind of theoretical methods can be selected in some these methods.Some Examples:

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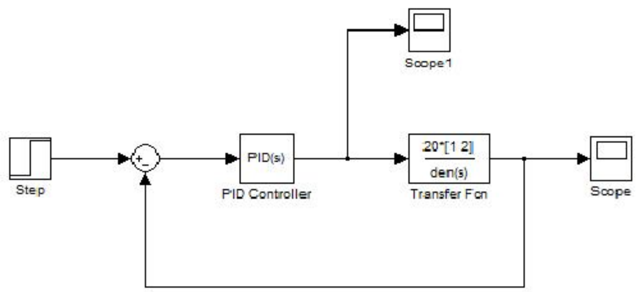
v. MATLAB Simulink PID Controller Tuning,

vi. BESTune, Exper Tune etc.



Implementation of controllers

There are three basic types of controllers: on-off, proportional and PID. Depending upon the system to be controlled, the operator will be able to use one type or the other to control the process.

i. Pneumatic On/Off controllers

The advantage of pneumatic controllers is its ruggedness while its major limitations are its slow response; it requires a clean and constant pressure air supply. The major components of a pneumatic controller are bellows, flapper nozzle amplifier, air relay and restrictors (valves). The integral and derivative actions are generated by controlling the passage of air flow through restrictors to the bellows. Here four bellows are connected to a force beam as shown. The measured process variable is converted to air pressure and connected to the bellows P_1. Similarly the air pressure corresponding to the set point signal is applied to the bellow P_2. The error corresponding to the measured value and the set point generates a force on the left hand side of the force beam. There is an adjustable pivot arrangement that sets the proportional gain of the amplifier. The right hand side of the force beam is connected to two bellows, $P_3$and P_4 and a flapper nozzle amplifier. The output air pressure is dependent on the gap between the flapper and nozzle. An air relay enhances the air handling capacity. The output pressure is directly fed back to the feedback bellows P_4, and also to P_3through a restrictor (valve). The opening of ths restrictor decides the integral action to be applied.

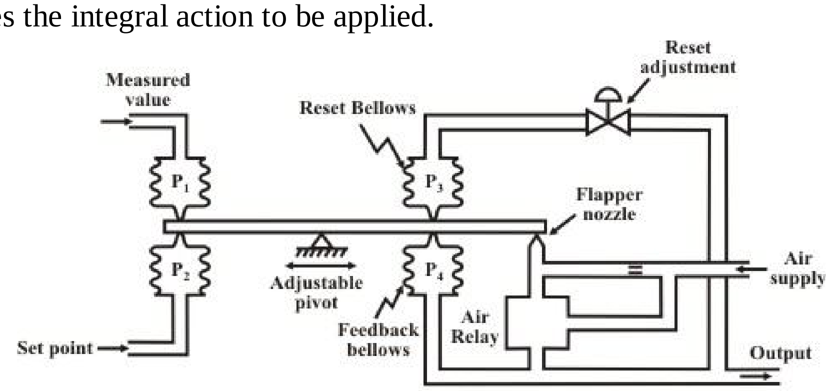


Fig. 4 A Pneumatic PI controller

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ii. Electrical On/Off controller

Trainees to discuss this control as their home assignment

iii. Pneumatic PID controllers

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iv. Electronic PID Controllers

Electronic PID controllers use operational amplifiers and passive components like resistors and capacitors as shown below;

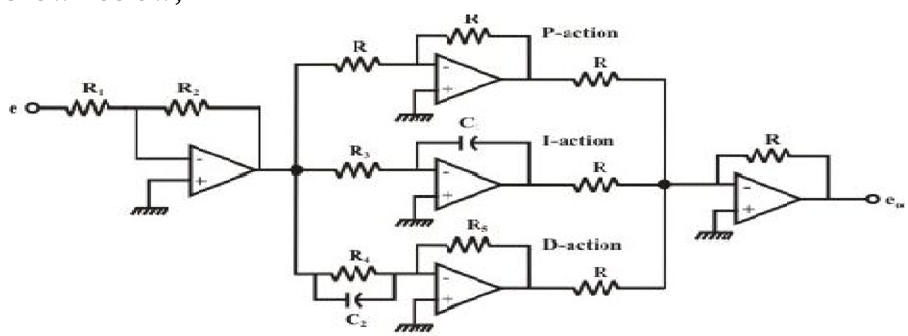

Fig. 5 Electronic PID controller

It can be shown that the circuit is capable of delivering the PID actions as:

$$u(t) = K_p[\ e(t) + \frac{1}{\tau i}\int \mathbf{e(\tau)}\, d\boldsymbol{\tau} + \boldsymbol{\tau}\mathbf{d}\frac{de(t)}{dt}]$$

The proportional gain $K_p$is decided by the ratio $R_2/R_1$of the first amplifier; the integral action is decided by $R_3$and $C_1$and the derivative action by $R_5$and C_2.The final output comes out with a negative sign, compared to the equation above.

v. Computer PID control Processor

In the digital or computer processor control mode, the error signal is first sampled and the controller output is computed numerically through a digital processor and becomes continuous-type P-I-D controller given by the expression:

$$u(t) = K_p[\ e(t) + \frac{1}{\tau i}\int \mathbf{e(\tau)}\, d\boldsymbol{\tau} + \boldsymbol{\tau}\mathbf{d}\frac{de(t)}{dt}]$$

The above equation can be implemented in two ways

1. **Position algorithm**

The above equation can be discretized at small sampling interval T_0as shown in the figure below.

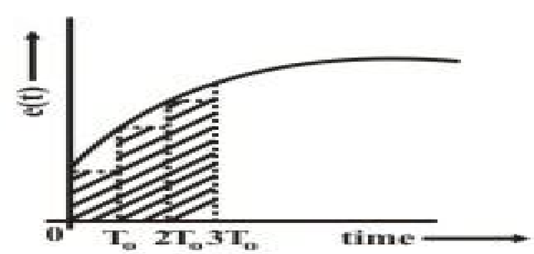

Fig. 6 Discretisation of the error signal

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Taking the first order derivative,

$$\frac{de}{dt} \Rightarrow \frac{1}{T0}[e(k) - (e)k - 1)$$

and using rectangular integration, we can approximate as:

$$\int_0^t e(\tau)dt \Rightarrow T_0 \sum_{i=0}^{k-1} e(i) \text{ ; } t = kT_0$$

Now replacing the derivative and integral terms one obtains,

$$u(k) = K_p[e(k) + \frac{T0}{\tau i}\sum_{i=0}^{k-1} e(i) \ + \frac{\tau d}{T0}[e(k) - (e)k - 1)$$

The above algorithm is known as *Position algorithm.*

2. Velocity algorithm

From the above expression, one can write the error signal at the (k-1)th instant as:

$$u(k-1) = K_p[e(k-1) + \frac{T0}{\tau i}\sum_{i=0}^{k-2} e(i) \ + \frac{\tau d}{T0}[e(k-1) - (e)k - 2)$$

Subtracting this equation from the previous expression, we have:

$$\Delta u(k) = u(k) - u(k-1)$$

$$= K_p[e(k) - e(k-1) + \frac{T0}{\tau i}e(k-1) + \frac{\tau d}{T0} \ \{e(k) - 2e(k-1) + e(k-2)\}]$$

$$= q_0e(k) + q_1e(k-1) + q_2e(k-2)$$

where,

$$q_0 = K_p(1 + \frac{\tau d}{T0})$$

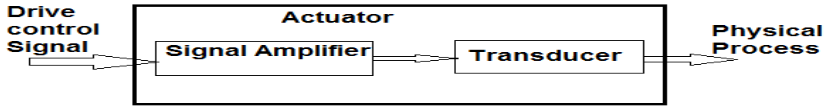
$$q_1 = -K_p(1 + \frac{\tau d}{T0} - \frac{T0}{\tau i})$$

$$q_2 = K_p\frac{\tau d}{T0}$$

The above algorithm is known as *Velocity algorithm*. The major advantage of this algorithm is that it is of recursive type and calculates the incremental output at each sample instant. As a result, it requires only to store three previous values: e(k), e(k-1) and e(k-2).

Actuators

An actuator is the device that brings about the mechanical movements required for any physical process in the factory. An actuator can be broken down into two separate modules: the signal amplifier and the transducer.



The Structure of an actuator

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The amplifier converts the (low power) control signal into a high power signal that is fed into the transducer; the transducer converts the energy of the amplified control signal into work; this process usually involves converting from one form of energy into another, e.g. electrical motors convert electrical energy into kinetic energy.There many types of actuators that include the following;

1. Hydraulic Actuators
2. Pneumatic Actuators
3. Solenoid Actuators
4. Digital stepper motor drives
5. Stepper motor drives
6. IC L298
7. IC SAA 1027

1. Pneumatic Actuators

Physical processes in pneumatic drives obey the gas laws that describes the relationship between thermodynamictemperature (T), pressure (P) and volume (V) of gases. Three of these laws, Boyle's law,Charles's law, and Gay-Lussac's law, when combined to form the combined gas law;

$$P_1V_1/T_1= P_2V_2/ T_2$$

which with the addition of Avogadro's law later gave way to the ideal gas law. Other important gas laws include Dalton's law of partial pressures. A gas that obeys these gas laws is known exactly as an ideal gas. The most important gas law is the ideal gas law, which states that:

$$PV = nRT$$

All pneumatic actuators can be subdivided into the following types:

- diaphragm pneumatic actuators;
- pneumatic power cylinders;
- gas-engine pneumatic actuators;
- turbine pneumatic actuators;
- jet-stream pneumatic actuators;
- pneumomuscles;
- combined pneumatic actuators.

Automatic pneumatic drive

It represents a complex of devices and consists of a source of gas energy, units of gas networks and mains (UGM), pneumatic amplifiers (PA), pneumatic engines (PE), the mechanism of transfer (MT) and directors, converting and summing device (CSD), amplifiers of capacity of electric signals (ACE), electromechanical converters (EMC), devices of feedbacks (DF), adjusting circuits AC) and internal feedbacks (IF).All complex of these devices is intended for amplification and transformation of a low-powerinput signal into mechanical moving of the target shaft of the executive mechanism. The initial drive size of a drive is electric signal U_{ip} of low power N_{ip}which is corrected and amplifies with the help of additional feed energy of the capacity amplifier in the converting and summing device (CSD).

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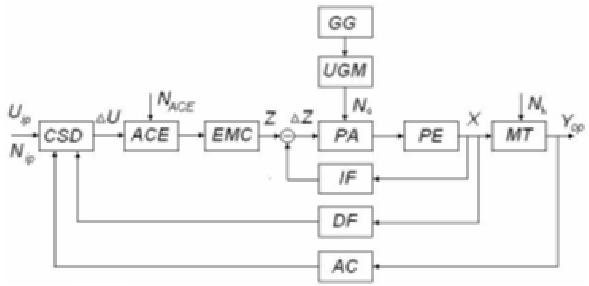
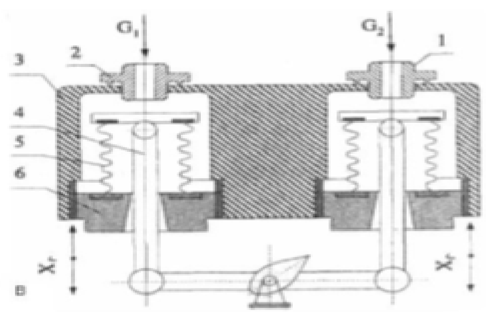


Automatic Pneumatic Drive

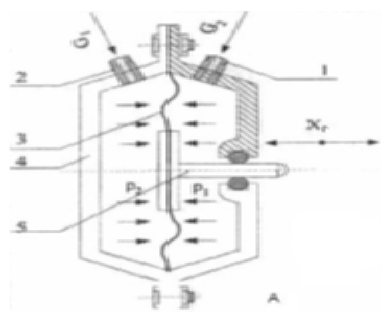
The amplified control signal moves on electromechanical converter (EMC) that accordingly moves the managing body of pneumoamplifier (PA) on the size value z. The angle of the turn of electromechanical converter's (EMC) axis in direct ratio corresponds to the size value z. To increase dynamic properties and accuracy of reproduction of the input signal the automated drive has feedbacks EF and DF and adjusting circuits (AC) on speed, acceleration
and loading.

a). Diaphragm pneumatic actuators

Diaphragm pneumatic actuators include membrane and sylphonpneumoactuators.



sylphon pneumatic actuator



membrane pneumatic actuator

Work of the pneumatic actuator consists in moving of a rod under influence of the difference of pressure p1 − p2 in cavities that is formed due to the difference of gas charges G1 − G2.

b). Pneumatic power cylinders

Air or pneumatic cylinders are devices that convert power of compressed air into mechanical energy. This mechanical energy produces linear or rotary motion. The air cylinderfunctions as the actuator in the pneumatic system, so it is also known as a pneumatic linearactuator.Devices with forward linear movement are divided into single-acting and double-actingpneumocylinders, with rod and rodless. Rod pneumocylinders in turn can have a through-passor a no-go rod. Devices with rotary (rotational) movement are divided into pneumocylinderswith rotary movement of the output link and rotational pneumocylinders.

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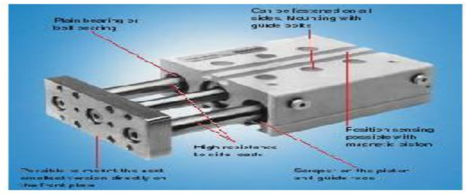
The ZSC series



The GPC series

c). Pneumomuscles

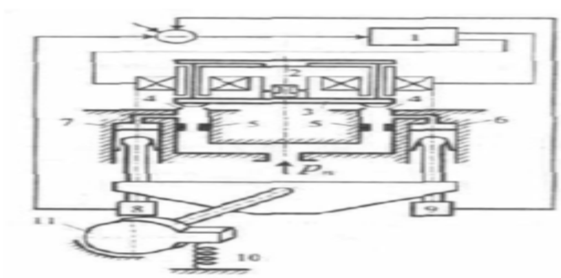
Pneumomuscles are linear pneumatic drives which can reproduce the movements similar to natural muscles. In comparison with power cylinders they develop the big initial efforts to the same working diameters. We distinguish lengthen and reduced pneumomuscles. Character of movement is defined with geometry of a braid of a pneumomuscle.

d). The combined pneumatic actuators

As shown in the figure below, the drive consumes gas from the source of constant pressure 1 of direct current, the electromechanical converter 2 with Ø-shaped stator, choker 3 that is elastic fixed on stator, nozzles 4, throttles 5, executive pneumocylinders 6 and 7, sensors 8 and 9 of feedback by speed and on position of a conducted link - the shaft connected to loading.Item loading is given by a spring 10, and inertial loading - a flywheel 11. Besides it is supposed, that the loading from hydraulic friction is also created.

Advantagesof Pneumatic Actuators:

a. simplicity of realization relatively to small back and forth motions;
b. sophisticated transfer mechanisms are not required;
c. low cost;
d. high speed of moving;
e. ease at reversion movements;
f. tolerance to overloads, up to a full stop;
g. high reliability of work;
h. explosion and fire safety;
i. ecological purity;
j. ability to accumulation and transportation.



The electropneumatic actuator

Disadvantagesof Pneumatic Actuators:

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a. compressibility of the air ;
b. impossibility to receive uniform -constant speed movement of working parts;
c. difficulties in performance at slow speed;
d. has limited conditions of use of compressed air
e. compressed air requires good preparation.

2. Hydraulic Actuators

Liquid is the physical body possessing fluidity. Fluidity is understood as easy mobility ofparticles. Due to fluidity, liquids show resistance to shift in direct dependence on speed of shift deformation andto compression. Taking into account mechanical properties we can distinguish two types of liquid: lowcompressible(dropping) liquids which insignificantly change the volume when temperatureand pressure change, and compressed (gaseous).Cavitation is accompaniedby formation of steam-to-gas bulbs that move with a stream of liquid in area with higherpressure, slam and radiate shock wave. Cavitation can arise at low pressure in pipelines, pumps - everywhere where the stream ofliquid is exposed to bends, to narrowing's expansion (valves, throttles, etc.) followed by.The original form, for incompressible flow in a uniform gravitational field (such as onEarth), is:

$$\frac{v2}{2} + gh + \frac{p}{\rho} = const.$$

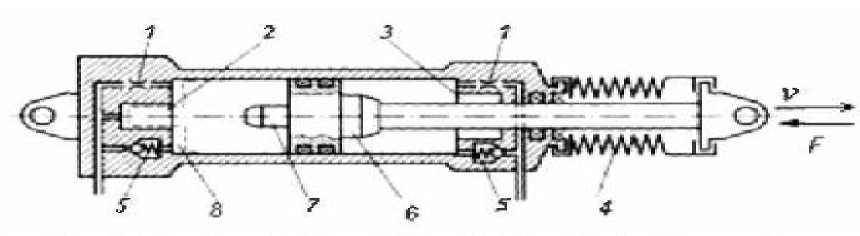
The equation is named after Daniel Bernoulli.The second Bernoulli's equation is written for compressiblefluids following the streamline flow:

$$\frac{v2}{2} + \varphi + \varphi = const.$$

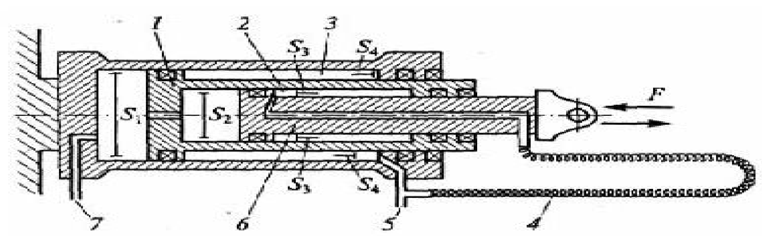
The constant on the right hand side is often called the Bernoulli constant and denoted **b**. For steadyinviscid adiabatic flow with no additional sources or sinks of energy, **b** is constant along any given streamline. When **b** may vary along streamlines, it still proves auseful parameter, related to the 'head" of the fluid. Hydraulic actuators include the following;

i. Hydraulic Cylinders

Hydraulic cylinders widely apply in building, digging, hoisting-and-transport, road machines, automobiles, and also in the processing equipment - metal-cutting machine tools, forge -pressing machines. The hydraulic cylinder of one- sided action has a plunger 1, moved by force of pressure of liquid to one side. Reverse motion of the plunger is made under action of external force F if it operates continuously, or spring 2. The unique external condensation of the plunger consists of the basic 3 and antisplash 4 condensing elements. The hydraulic cylinder of double-sided action has the piston 5 with a rod 7, condensed by internal 6 and external 8 sealants.



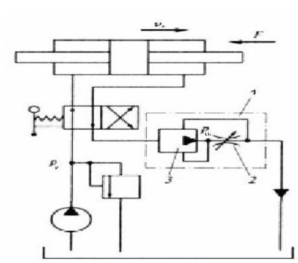
The hydraulic cylinder with trailer throttle brakes and the protected rod



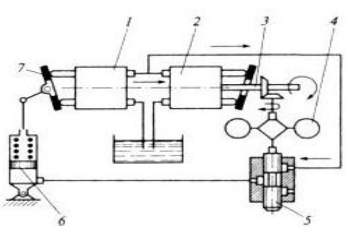
The telescopic hydraulic cylinder

ii. Volumetric hydraulic actuator

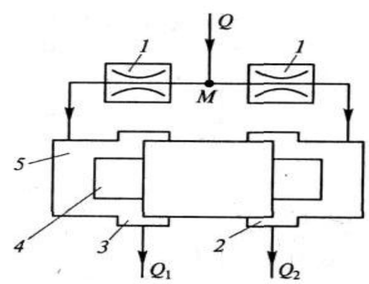
Volumetric hydraulic actuator is the set of volumetric hydromachines, hydroequipments, hydrolines(pipelines) and the auxiliary devices, intended to transfer energy and transformation of movement by means of liquid.There are several types of pumps and hydraulic engines, which can be considered as hydromashines.



The scheme of a hydraulic actuator with a regulator of a stream



The scheme of a hydraulic actuator with steady output rotation frequency



The scheme of a stream divider

Advantages of Hydraulic Actuators

Variable hydraulic actuators are widely used as drives of machine tools, rolling mills, pressingand the foundry equipment, road and building machines, transport and agricultural machines,etc. Actuators can be applied in the following areas;

a. Pneumatic processing centers

The scheme of the pneumatic processing center with a rotary table is submitted in figure below. All actuators of the center, including a drive of the tool are pneumatic. Simultaneousmovement of several drives achieves any trajectory of sawing material.

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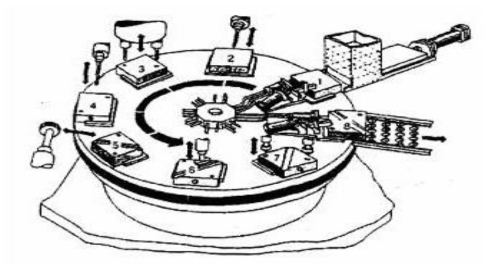
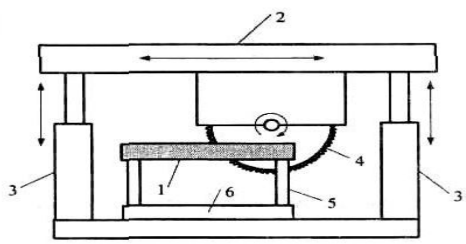


The scheme of the pneumatic machining center



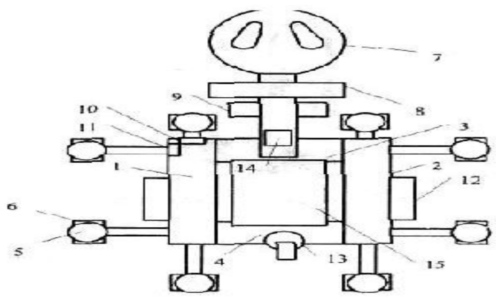
The scheme of the pneumatic processing center for sawing materials

b. Batching

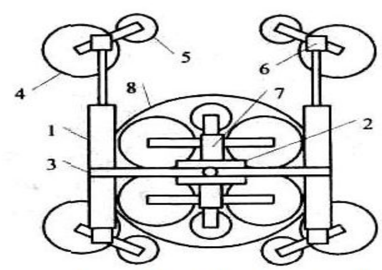
Batching of liquids and the fused metals are foundry manufacture can be madeby system which circuit is shown in figure below. The lever with a ladle is actuated by the power cylinder.

c. Robotics

On the basis of pneumatic actuators stationary and mobile robots with wide functionalities can be created.One of the first stationary Russian serial pneumatic industrial robots is M¨I - 9 ˜N.The robot has four degrees of mobility provided by horizontal and vertical power cylinders, and also by a turning drive of gripping device and a drive of fingers.Mobile pneumatic robots allow to realize walking type of moving.



The scheme of the mobile robot



The scheme of the mobile robot with vertical displacement

3. The IC L298

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4. The IC SAA1027

Trainees to discuss this as homework assignment

5. Solenoid Actuators

Trainees to discuss this as homework assignment

6. Stepper motor drives

Stepper motors rotate in discrete steps (e.g. 2° for each step) and have many uses in motion for robots and locating or indexing tables. Their working principle is similar to DC motors, but they are controlled by digital electronics: an electronic circuit turns a series of switches ON and OFF at each electrical pulse input to the stepper motor control. The stepper motor is driven by feeding

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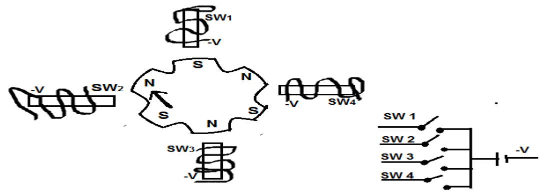
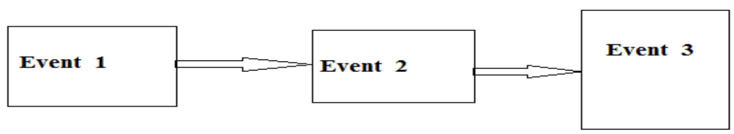
it a stream of electric pulses. Each pulse makes the motor rotate by a fixed angle. Figure below shows a simple stepper motor.



TOPIC THREE
SEQUENTIAL CONTROL SYSTEMS

Sequence control

It is a process in which one event follows another until a job is completed. This is done in a serial arrangement in which things follow in logical order or a recurrent pattern.



Sequence of events

It is applied in the assembly line process, conveyor systems, industrial robots, power protection systems, motor starting and control systems etc. and it is characterized by;

i. Discrete loads
ii. Product output is in units or boxes
iii. Different equipment modifies the product at each step
iv. Steps are staged

Time delay units

A time delay unit is a structure that provides a specific time delay, or programmable time delay, using a multi-path structure. The two states are only slightly different in time delay, and certainly the two states differ in path length by less than a wavelength. A TDU provide many wavelengths of phase shift, and the phase shift is ideally exactly proportional to frequency such that the group delay difference between the two states is flat over the required bandwidth. TDUs are used in phased arrays. Phase shifters at each element steer the beam, but they do not provide true time delay. Without true time delay, the beam will distort over frequency. Time delay can be accomplished in many ways:

i. The most natural way is to use a length of coax; the rule of thumb one nanosecond per foot applies to air coax, PTFE filled coax (ER=2.2) will provide eight inches.

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ii. Another way to provide time delay is using fiber optic delay line. Here you will have to convert microwaves to light and back again. Amplification means the delay line will be non-reciprocal, and you will need separate TDUs for transmit and receive, or some means of turning the amplifiers around.

iii. Delay lines can be made using microstrip, stripline, or coax.

The following are some relevant specifications for TDUs:

i. Bandwidth
ii. Insertion loss
iii. Total time delay (expressed in nanoseconds or picoseconds)
iv. Time delay flatness over frequency (expressed in %)
v. Number of bits
vi. Amplitude matching over delay states
vii. Amplitude tracking over frequency

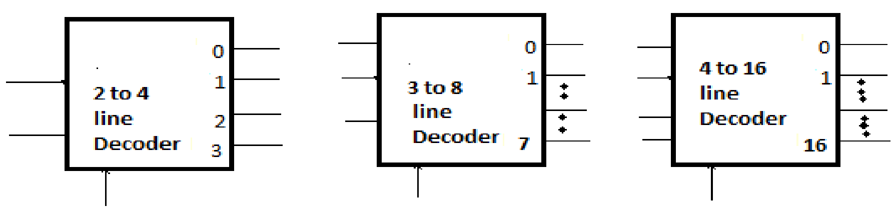
Time delay units can be in the following ways:

1. Control relays
2. Digital relays
3. Analogue relays

Decoders and Encoders

Decoders

A *decoder* is a special case of a demultiplexer without the input line and therefore it is a combinational circuit that decodes the information on ***n*** input lines to a maximum of 2^n unique output lines. The figures below show the circuit representation of three decoders which are the 2-to-4 decoder, 3-to-8 decoder and 4-to-16 line decoder.



Circuit of conversion of decoders

If there are some unused or combinations which are also called '*don't care*' combinations in the n-bit code, then there will be fewer than 2^n output lines. This means that if there are 3-input lines, then the maximum of outputs expected are eight unique output lines. If this was a 3-bit input code where the only used 3-bit combinations are simply given as ***000, 001, 010, 100, 110*** and ***111***, then this decoder will have only six output lines. In this case, 011 and 101 are being either unused or taken as don't care combinations. It is therefore general taken as if ***n*** and ***m*** are the numbers of input and output lines respectively, then m and n relates as, $\mathbf{m \leq 2^n}$. Decoders generate a maximum of 2^n possible minterms with an n-bit binary code.

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INPUTS			OUTPUTS							
A	B	C	D_0	D_1	D_2	D_3	D_4	D_5	D_6	D_7
0	0	0	1	0	0	0	0	0	0	0
0	0	1	0	1	0	0	0	0	0	0
0	1	0	0	0	1	0	0	0	0	0
0	1	1	0	0	0	1	0	0	0	0
1	0	0	0	0	0	0	1	0	0	0
1	0	1	0	0	0	0	0	1	0	0
1	1	0	0	0	0	0	0	0	1	0
1	1	1	0	0	0	0	0	0	0	1

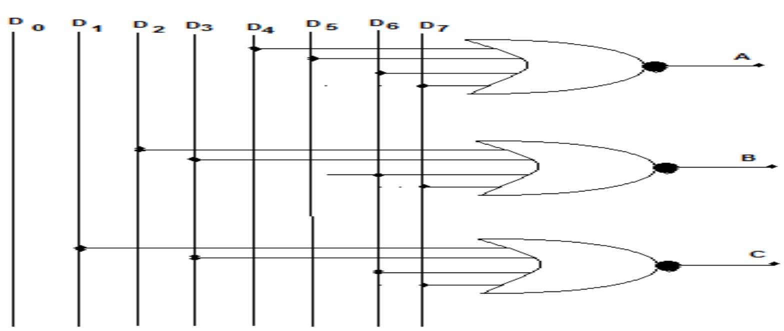
The truth table above is of a logic circuit that implements a 3-to-8 line decoder function where this decoder has three inputs designated as A, B and C and eight outputs as D_0, D_1, D_2, D_3, D_4, D_5, D_6 and D_7.

Encoders

An encoderis a multiplexer without its single output line. It is truly a combinational logic function that has $\mathbf{2^n}$ or even fewer input lines and **n** output lines. This corresponds to **n** selection lines in any multiplexer. The n output lines generate the binary code for the possible 2^n input lines. For an octal-to-binary encoder, its encoder would have eight input lines where each will represent an octal digit and three output lines representing the three-bit binary equivalent. The truth table of such an encoder is given in the figure below where D_0 to D_7 represent octal digits 0 to 7 and the A, B, and C only represent binary digits.

D_0	D_1	D_2	D_3	D_4	D_5	D_6	D_7	A	B	C
1	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	1
0	0	1	0	0	0	0	0	0	1	0
0	0	0	1	0	0	0	0	0	1	1
0	0	0	0	1	0	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0	1
0	0	0	0	0	0	1	0	0	1	0
0	0	0	0	0	0	0	1	1	1	1

Truth table of an encoder



Octal-to-binary encoder

The figure above shows the hardware implementation of the octal-to-binary encoder described by the truth table. It is noted here also that this circuit has the shortcoming that it produces an all 0s output sequence when all input lines are in logic '0' state but it solved by having an additional line to indicate an all 0s input sequence.For this eight input lines, would have 2^8= 256 possible combinations but in an octal-to-binary encoder, only eight of these 256 combinations

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would have any physical meaning as shown in the above truth table. The remaining 248 combinations of input variables are the ‘***don’t care’*** input combinations. It is also noted that only one of the input lines at a time is in logic ‘1’ state.

Interlock Systems

Interlocking

Interlocking is defined as an arrangement of signals and signal appliances so interconnected that their movements must succeed each other in proper sequence". In railway signaling, an interlockingis an arrangement of signal apparatus that prevents conflicting movements through an arrangement of tracks such as junctions or crossings. The signaling appliances and tracksare sometimes collectively referred to as an interlocking plant or system. Some of the fundamental principles of interlocking include:

- Signals are not operated to allow conflicting motion to take place at the same time.
- Switches and other appliances in the route must be properly 'set' (in position) before a signal is allowed to enter that route.
- Once a route is ***set***and a motion is given a signal to proceed over that route, all switches and other movable appliances in the route are locked in position until next signal.

Types of Interlocking

Interlocking can be categorized as;

i. Mechanical or analogue
ii. Electrical (solenoid or electro-mechanical or control relay-based.
iii. Limit Switches are electro-mechanical devices that consist of an actuator mechanically linked to a set of contacts. When an object comes into contact with the actuator, the device operates the contacts to make or break an electrical connection. Our limit switches work in a variety of applications and environments because of their ruggedness, simple visible operation, easy installation and reliable operation
iv. Electronic/computer-based digital.

a. Mechanical interlocking

In mechanical interlocking plants, a *locking bed*is constructed that consists of steel bars forming a grid. The levers that operate switches, derails, signals or other appliances are connected to the bars running in one direction. The bars are constructed so that, if the function controlled by a given lever conflicts with that controlled by another lever, mechanical interference is set up in the *cross locking* between the two bars, in turn preventing the conflicting lever movement from being made.

b. Electro-mechanical interlocking

Power interlocking may use mechanical locking to ensure the proper sequencing of levers, but the levers are considerably smaller as they themselves do not directly control the field devices. If

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the lever is free to move based on the locking bed, contacts on the levers actuate the switches and signals which are operated electrically or electro-pneumatically. Before a control lever may be moved into a position which would release other levers, an indication must be received from the field element that it has actually moved into the position requested.

Part of a relay interlocking using miniature plug-in relays

Interlocking is effected purely electrically consist of complex circuitry made up of relays in an arrangement of relay logic that ascertain the state or position of each signal appliance. As appliances are operated, their change of position opens some circuits that lock out other appliances that would conflict with the new position.

c. **Entrance-Exit Interlocking (NX)**

The NX system allowed an operator looking at the diagram of a complicated junction to simply push a button on the known entrance track and another button on the desired exit track, and the logic circuitry handled all the necessary actions of commanding the underlying relay interlocking to set signals and throw switches in the proper sequence as required to provide valid route through the interlocking plant.

d. Electronic interlocking

Modern interlocking are solid state devices where the wired networks of relays are replaced by software logic running on special-purpose control hardware. The logic is implemented by software needed by reprogramming rather than hard-wired circuitry.

Computer-based electronic interlocking

e. **Solid State Interlocking** (SSI)

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This is the first generation microprocessor-based interlocking. Second generation processor-based interlockings are known by the term "Computer Based Interlocking" (CBI).

Forms of locking

Electric locking

The combination of one or more electric locks or controlling circuits by means of which levers in an interlocking machine, or switches or other devices operated in connection with signaling and interlocking are secured against operation under certain conditions.

Section locking

Electric locking is effective while a train occupies a given section of a route and adapted to prevent manipulation of levers that would endanger the train while it is within that section.

Route locking

Electric locking take effect when a train passes a signal is adapted to prevent manipulation of levers that would endanger the train while it is within the limits of the route entered.

Approach locking

Electric locking effective while a train is approaching a signal that has been set for it to proceed and adapted to prevent manipulation of levers or devices that would endanger that train.

Stick locking

Electric locking taking effect upon the setting of a signal for a train to proceed, released by a passing train, and adapted to prevent manipulation of levers that would endanger an approaching train.

Indication locking

Electric locking adapted to prevent any manipulation of levers that would bring about an unsafe condition in case a signal, switch, or other operated device fails to make a movement corresponding with that of the operating lever.

Check locking or traffic locking

Electric locking that enforces cooperation between the Operators at two adjacent plants in such a manner that prevents opposing signals governing the same track from being set to proceed at the same time.

Programmable Logic Controllers (PLC)

A PLC is an industrial computer control system that continuously monitors the state of input devices and makes decisions based upon a custom program to control the state of output devices. Almost any production line, machine function, or process can be greatly enhanced using this type of control system. However, the biggest benefit in using a PLC is the ability to change and replicate the operation or process while collecting and communicating vital information. Programmable Logic Controller (PLC) also known as Industrial Computer is the major

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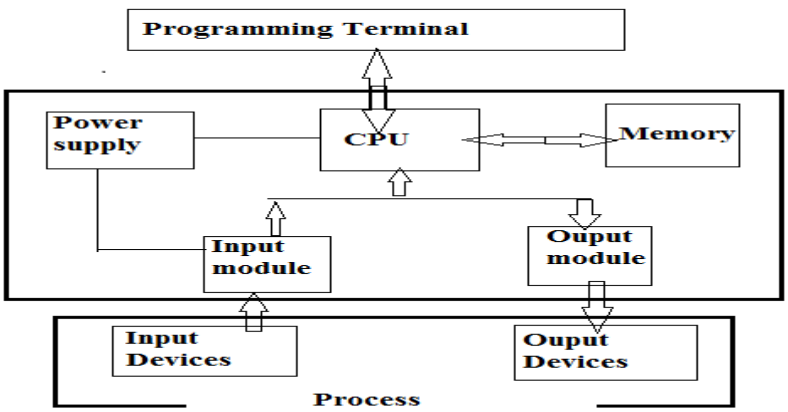
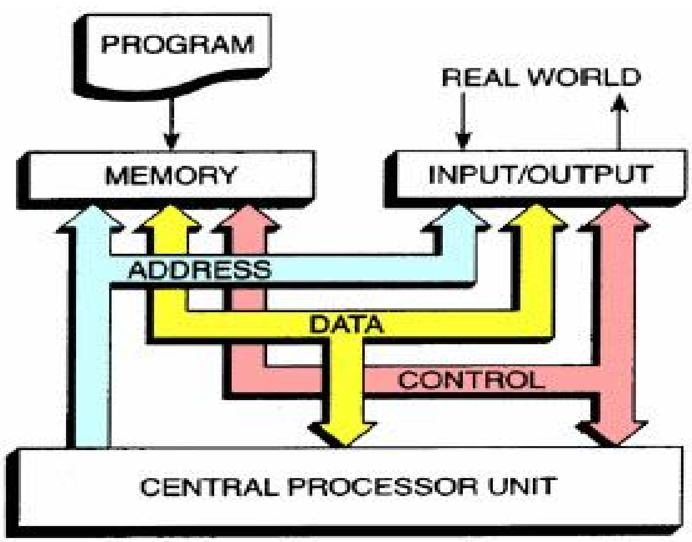
component in the industrial automation sector. They contain functional features like PID controllers, sequential control, timers and counters, ease of programming, reliable controlling capabilities and ease of hardware usage.The PLC is designed as a replacement for the hardwired relay and timer logic to be found in traditional control panels, where PLC provides ease and flexibility of control based on programming and executing logic instructions. The internal functions such as timers, counters and shift registers making sophisticated control possible using even the smallest PLC. The structure of a PLC can be divided into four parts. They are input/output modules, central processing unit (CPU), memory and programming terminal.PLCs are also a special-purpose digital computer in industries as well as in other control-system areas. PLCs are capable of monitoring the inputs continuously from sensors and producing the output decisions to operate the actuators based on the program. PLCs are manufactured by companies like;Moellers, Mitsubishi, Eaton and Siemens. Every PLC system needs at least these three modules:





PLC Architecture

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Homework

Trainees to do the following as an home assignment

Discuss the following LCs

i. Moellers,

ii. Mitsubishi,

iii. Eaton

iv. Siemens.

1. The CPU of a PLC Module

CPU module consists of a central processor and its memory. The Processor is responsible for doing all the necessary computations and data processing by accepting the inputs and producing appropriate outputs. Memory includes both ROM and RAM memories.

The ROM memory contains the operating system, driver and application programs, whereas the RAM stores user-written programs and working data. These PLCs use retentive memory to save user programs and data when the power supply breaks or fails and to resume the execution of a user program ones the power is restored. Thus, these PLCs do not need any use of a keyboard or monitor for reprograming the processor each time. The retentive memory can be implemented with the use of long-life batteries, EEPROM modules and flash memory methods.

BUS or Rack

This bus enables the communication between CPU and I/O modules to send or receive the data. This communication is established by addressing the I/O modules according to the location fromCPU module along the bus. Some buses provide necessary power to I/O module circuitry, but they do not provide any power to sensors and actuators connected to I/O modules.

PLC BUS or Rack

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2. Power Supply Module

These modules supply the necessary power required for the whole system by converting the available AC power to DC power required for CPU and I/O modules. The output 5V DC drives the computer circuitry, and in some PLCs 24DC on the bus rack drives few sensors and actuators.

Power Supply Module

3. Input/Output Modules

Input and output modules of PLCs allow connection to sensors and actuators to the system to sense or control the real-time variables such as temperature, pressure flow, etc. These I/O modules vary in type, range, and capabilities and some of these include the following:

PLC I/O modules

i. Digital I/O module:

These are used to connect the sensors and actuator that are of digital in nature, i.e. only for switch ON and OFF purpose. These modules are available on both AC and DC voltages and currents with variable number of digital inputs and outputs.

ii. Analog I/O modules:

These are used to connect the sensors and actuators that provide the analog electric signals. Inside these modules, analog to digital converter is used to convert the analog to processor understandable data, i.e., digital data. This module’s number of channel’s availability is also can be varied depending on the application

iv. Communication Interface Modules:

These are intelligent I/O modules that exchange the information between a CPU and communication network. These are used for communicating with other PLCs and computers that are placed at a remote or far away distance.

Types of Programmable Logic Controllers (PLCs)

PLCs are considered to be in the form of:

a. Integrated units

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b. Single or modular units.

An integrated or Compact PLC
It is built by several modules within a single case and its I/O capabilities are decided by the manufacturer, but not by the user.

A modular PLC
It is built with several components that are plugged into a common rack or bus with extendable I/O capabilities. It contains power supply module, CPU and other I/O modules that are plugged together in the same rack, which are from same manufacturers or from other manufacturers. These modular PLCs come in different sizes with variable power supply, computing capabilities, I/O connectivity, etc.Modular PLCs are further divided into small, medium and large PLCs based on the programmemory size and the number of I/O features.

Sizes of PLCs

a. **Small PLC**
   - is a mini-sized PLC that is designed as compact and robust unit mounted or placed beside the equipment to be controlled. This type of PLC is used for replacing hard-wired relay logics, counters, timers, etc. This PLC I/O module expandability is limited for one or two modules and it uses logic instruction list or relay ladder language as programming language.

b. **Medium-sized PLC**
   - is mostly used PLC in industries which allows many plug-in modules that are mounted on backplane of the system. Some hundreds of input/ output points are provided by adding additional I/O cards – and, in addition to these – communication module facilities are provided by this PLC.

c. **Large PLCs**
   - are used wherein complex process control functions are required. These PLCs' capacities are quite higher than the medium PLCs in terms of memory, programming languages, I/O points, and communication modules, and so on.

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Mostly, these PLCs are used in supervisory control and data acquisition (SCADA) systems, larger plants, distributed control systems, etc.

Many types of programmable logic controller are used in the manufacturing industry. They are defined by the physical configuration of their hardware as well as the types of software or programming languages used. Programmable logic controller hardware is built to withstand intense weather or physical wear and software is often made to be somewhat elastic to accommodate many different situations. As a result, the various controllers are often designed for manufacturing and automation systems.

Types of PLCS

The different types can include;

i. **Ladder logic**

Ladder logic is one of the most common programmable logic controller types. Relay logic hardware is automated and maintained using programmable logic. This makes this type useful in industrial systems, because many functions can be maintained with minimal human interaction. Ladder logic can be combined with multiple forms of programmable controllers to create advanced systems.

ii. Traditional programming

Traditional programming logic controllers use common computer languages, such as BASIC, to input commands and maintain a system. This type includes some level of human interaction. They might be used to control relay-based systems or factory manufacturing processes that must be flexible.

iii. State logic

State logic is considered to be one of the flexible types of programmable logic controller. By building a computerized model of a real-world task, programmable state logic controllers are used to assist with tasks that might change quickly. State logic allows for simulation of decision-making because the state of a program will change based on input and output data.

iv. Human-machine interface

Human-machine interfaces combine the different controllers to allow for automation and routine human interaction. These systems rely on input commands to provide data to users when requested. This type is more advanced and fully automated systems because various programming languages are needed to facilitate consistent interaction.

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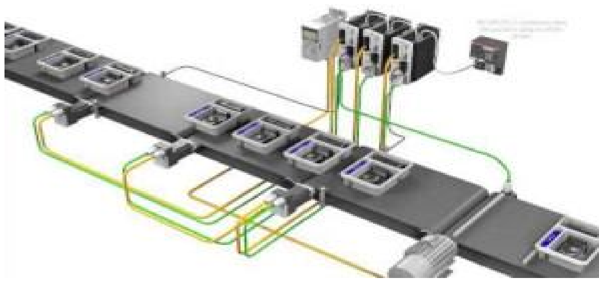
v. **Remote terminal units**

Remote terminal units are designed to provide a static function. They are used remotely to provide a consistent stream of data despite harsh environmental or data-processing conditions. These systems are designed to function without much human interaction which can make them ideal for monitoring when compared to other control systems.

Applications of PLC

1. Below is a PLC for a simple process control wherein the conveyor belt operation, the position sensor and other sensor outputs are connected to the input module of the PLC, and from the output modules – a motor is controlled. When the sensors are activated, then the CPU of the PLC reads the inputs, and correspondingly processes them according to the program and produces the outputs to operate the motor so that the conveyor is controlled.


Applications of PLC

2. PLC and SCADA combination of control structure is used in industrial automation sector and also in electrical utility systems like power transmission and distribution systems. Programmable sequential switching operation is another major application area of the PLC.

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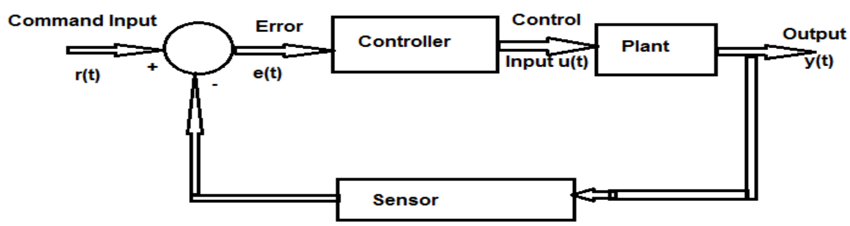
TOPIC FOUR
DIGITAL CONTROL SYSTEMS

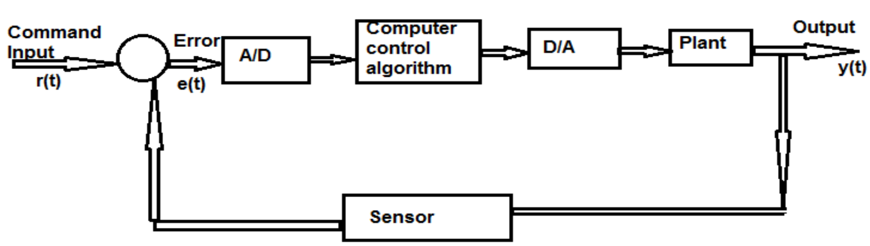
Digital control systems

A digital control system model can be viewed from different perspectives including control algorithm, computer program, conversion between analog and digital domains, system performance etc. The most important aspects is the sampling process level. In continuous time control systems, all the system variables are continuous signals. Whether the system is linear or nonlinear, all variables are continuously present and therefore known at all times. A continuous time control system is shown in Figure below.



A typical closed loop continuous time control system

In a digital control system, the control algorithm is implemented in a digital computer. The error signal is discretized and fed to the computer by using an A/D (analog to digital) converter. The controller output is again a discrete signal which is applied to the plant after using a D/A (digital to analog) converter. General block diagram of a digital control system is shown in Figure below. The values of error, ***e(t)*** is sampled at intervals of time, **T**. In the context of control and communication, sampling is a process by which a continuous time signal is converted into a sequence of numbers at discrete time intervals. It is a fundamental property of digital control systems because of the discrete nature of operation of digital computer.



General block diagram of a digital control system

Digital electronics are electronics that represent signals by discrete bands of analoglevels, rather than by continuous range. All levels within a band represent the same signal state. Digital

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techniques are useful because it is easier to get an electronic device to switch into one of a number of known states than to accurately reproduce a continuous range of values. A sequential system is a combinational system with some of the outputs fed back as inputs. This makes the digital machine perform a "sequence" of operations. The simplest sequential system is a mechanism that represents a binarydigit or "bit". Sequential systems divide into two further subcategories. "Synchronous" sequential systems change state all at once, when a "clock" signal changes state. "Asynchronous" sequential systems propagate changes whenever inputs change. Synchronous sequential systems are made of well-characterized asynchronous circuits such as flip-flops that change only when the clock changes and which have carefully designed timing margins. To implement a synchronous sequential state machine is to divide it into a piece of combinational logic and a set of flip flops called a "state register’. Each time a clock signal ticks, the state register captures the feedback generated from the previous state of the combinational logic and feeds it back as an unchanging input to the combinational part of the state machine. The fastest rate of the clock is set by the most time-consuming logic calculation in the combinational logic. Many systems need circuits that allow external unsynchronized signals to enter synchronous logic circuits. These are inherently asynchronous in their design and must be analyzed as such. Examples of widely used asynchronous circuits include synchronizer flip-flops, switch de-bouncers and arbiters.

Alarms

One-alarm, two-alarm, three-alarm fires, are categories of fires indicating the level of response by local authorities with an elevated number of alarms indicating increased commitment of resources. The term multiple-alarm is a quick way of indicating that a fire was severe and difficult to contain. The multi-alarm designation is based on the number of units responding to a fire; the more vehicles and firefighters responding, the higher the alarm designation. With this unit/firefighter alarm designation, the initial dispatch is referred to as a "first alarm" and is the largest. Subsequent alarms are calls for additional units.

Computer Data Logging

Data Logger

A data logger is an electronic instrument that records measurements at set intervals over a period of time. It is an electronic device that records data over time or in relation to location either with a built in instrument or sensor or via external instruments and sensors. Such measurements include: air temperature, relative humidity, AC/DC current and voltage, differential pressure, time-of-use, light intensity, water temperature, water level, dissolved oxygen, soil moisture, rainfall, wind speed and direction, leaf wetness, pulse signals, room occupancy and plug load.Data loggers are compact, battery-powered devices equipped with an internal microprocessor, data storage, and one or more sensors and equipped with a microprocessor, internal memory for data storage and sensors. They can be deployed indoors, outdoors, underwater and can record data for up to months at a time, unattended. A data logger may be a single-unit, stand-alone device with internal sensors, which fits in the palm of a hand, or it may

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be a multi-channel data collection instrument equipped with one or more external sensors.Some data loggers interface with a personal computer and utilize software to activate the data logger and view and analyze the collected data, while others have a local interface device (keypad, LCD) and can be used as a stand-alone device.

How a Data Logger Works

The data logger is connected to a computer through a USB interface. Next, accompanying data logger software is used to select logging parameters (sampling intervals, start time, etc.) and activate the logger. The logger is then disconnected and deployed in the desired location, where it records each measurement and stores it in memory along with the time and date. Bluetooth Smart loggers can be configured and launched wirelessly, after deployment. After the desired monitoring period, the data logger is then reconnected to the computer and the software is used again to read out the data and display the measurements in graphs that show profiles over time.

Tabular data can be viewed as well, or exported to a spreadsheet for further manipulation. In the case of web-based data logging systems, data are pushed to the Internet for access; with wireless data nodes, data are transmitted to a central receiver; and with Bluetooth Smart loggers, data are downloaded directly to your mobile device.Data loggers are used in a broad range of indoor, outdoor and underwater environments – essentially anywhere data is needed and the convenience of battery power is preferred.The four main types of data loggers include;

i. **Stand-alone data loggers**

   Stand-alone USB data loggers are compact, reusable, and portable, and offer low cost and easy setup and deployment. Internal-sensor models are used for monitoring at the logger location, while external-sensor models can be used for monitoring at some distance from the logger. Most stand-alone loggers communicate with a computer via a USB interface

ii. **Web-based data logging systems**

   Web-based data logging systems enable remote, around-the-clock Internet-based access to data via GSM cellular, WI-FI, or Ethernet communications. These systems can be configured with a variety of external plug-in sensors and transmit collected data to a secure web server for accessing the data.

iii. **Wireless data nodes**

   Wireless data nodes transmit real-time data from dozens of points to a central computer, eliminating the need to manually retrieve and offload data from individual data loggers.

iv. **Bluetooth Smart data loggers**

   Bluetooth Smart enabled data loggers measure and transmit temperature and relative humidity data wirelessly to mobile devices over a 100-foot range.

For greater convenience, a data shuttle device can be used to offload data from the logger for transport back to a computer.

Applications

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Applications of data logging include:

- ✓ Unattended weather station recording (such as wind speed / direction, temperature, relative humidity, solar radiation).
- ✓ Unattended hydrographic recording (such as water level, water depth, water flow, water pH, water conductivity).
- ✓ Unattended soil moisture level recording.
- ✓ Unattended gas pressure recording.
- ✓ Offshore buoys for recording a variety of environmental conditions.
- ✓ Road traffic counting.
- ✓ Measure temperatures (humidity, etc.) of perishables during shipments:
- ✓ Measure variations in light intensity.
- ✓ Process monitoring for maintenance and troubleshooting applications.
- ✓ Process monitoring to verify warranty conditions
- ✓ Wildlife research with pop-up archival tags
- ✓ Measure vibration and handling shock (drop height) environment of distribution packaging.
- ✓ Tank level monitoring.
- ✓ Deformation monitoring of any object with geodetic or geotechnical sensors controlled by an automatic deformation monitoring system.
- ✓ Environmental monitoring.
- ✓ Vehicle Testing (including crash testing)
- ✓ Motor Racing
- ✓ Monitoring of relay status in railway signaling.
- ✓ For science education enabling 'measurement', 'scientific investigation' and an appreciation of 'change'
- ✓ Record trend data at regular intervals in veterinary vital signs monitoring.
- ✓ Load profile recording for energy consumption management.
- ✓ Temperature, Humidity and Power use for Heating and Air conditioning efficiency studies.
- ✓ Water level monitoring for groundwater studies.
- ✓ Digital electronic bus sniffer for debug and validation

The Multiplexer

The multiplexer, ("MUX" or "MPX"), is a combinational logic circuit designed to switch one of several input lines through to a single common output line by the application of a control signal. Multiplexers operate like very fast acting multiple position rotary switches connecting or controlling multiple input lines called "channels" one at a time to the output. They can be digital circuits made from high speed logic gates used to switch digital or binary data or they can be analogue types using transistors and relays to switch one of the voltage or current inputs through to a single output.

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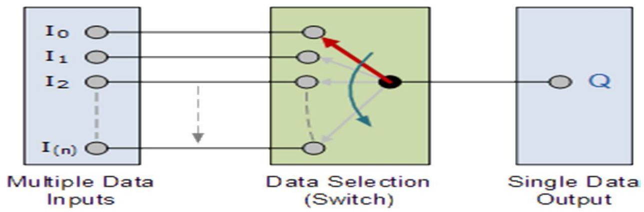
Multiplexing

Multiplexing is a term used to describe the operation of sending one or more analogue or digital signals over a common transmission line at different times or speeds. The device used is called a **Multiplexer**. The most basic type of multiplexer device is that of a one-way rotary switch as shown below.



Multiplexers are also known as data selectors because they can "select" each input line. They are used as one method of reducing the number of logic gates required in a circuit design or when a single data line or data bus is required to carry two or more different digital signals. The selection of each input line in a multiplexer is controlled by an additional set of inputs called *control lines* and according to the binary condition of these control inputs, either "HIGH" or "LOW" the appropriate data input is connected directly to the output. A multiplexer has an even number of 2^N data input lines and a number of "control" inputs that correspond with the number of data inputs.

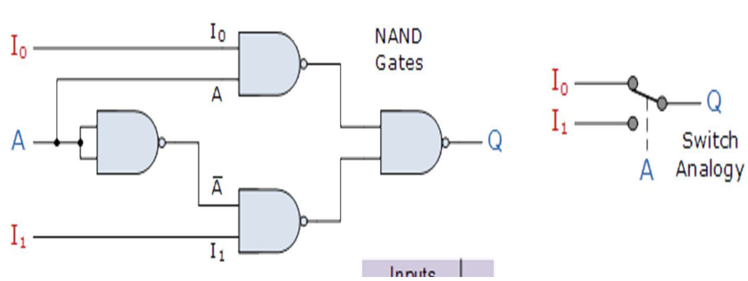
2-input Multiplexer Design

The input A of this simple 2-1 line multiplexer circuit constructed from standard NAND gate acts to control which input (I_0 or I_1) gets passed to the output at Q. From the truth table we can see that when data select input, A is LOW (logic 0), input I_1 passes its data to the output while input I0 is blocked. When data select A is HIGH (logic 1), input I0 is passed to Q while input I0 is blocked. So by the application of either a logic "0" or a logic "1" at A we can select the appropriate input with the circuit acting a bit like a single pole double throw (SPDT) switch. The 2-input multiplexer connects one of two 1-bit sources to a common output, producing a 2-to-1-line multiplexer and we can confirm this in the following Boolean expression.

$$\mathbf{Q = A.I_0.I_1 + A.I_0.I_1 + A.I_0.I_1 + A.I_0.I_1}$$

and for our 2-input multiplexer circuit above, this can be simplified too:

$$\mathbf{Q = A.I_1 + A.I_0}$$



A	I_1	I_0	Q
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	1

Truth Table

We can increase the number of data inputs to be selected further simply by following the same

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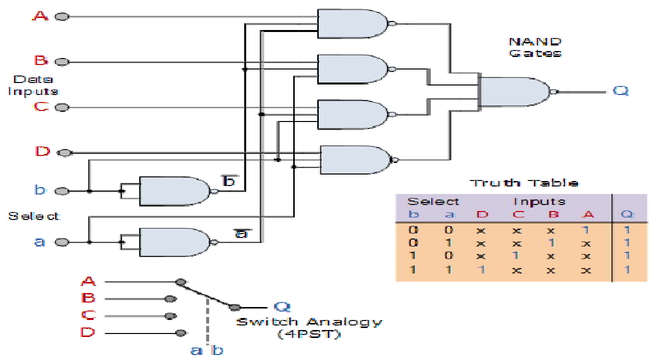
procedure and larger multiplexer circuits can be implemented using smaller 2-to-1 multiplexers as their basic building blocks. So for a 4-input multiplexer we would therefore require two data select lines as 4-inputs represents 22 data control lines give a circuit with four inputs, I_0, I_1, I_2, I_3 and two data select lines A and B as shown.

4-to-1 Channel Multiplexer

The Boolean expression for this 4-to-1 **Multiplexer** above with inputs **A** to **D** and data select lines**a, b** is given as:

Q = abA + abB + abC + abD



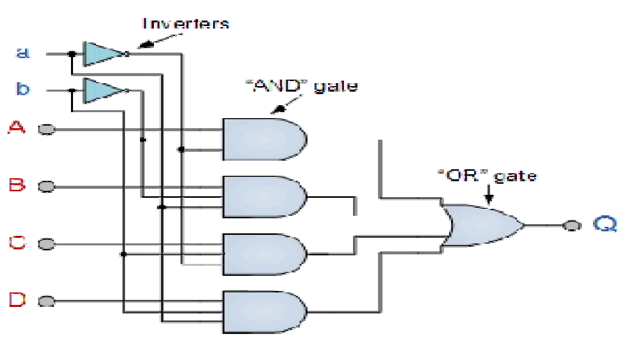
Select		Inputs				
b	a	D	C	B	A	Q
0	0	x	x	x	1	1
0	1	x	x	1	x	1
1	0	x	1	x	x	1
1	1	1	x	x	x	1

In this example at any one instant in time only ONE of the four analogue switches is closed, connecting only one of the input lines **A** to **D** to the single output at **Q**. As to which switch is closed depends upon the addressing input code on lines **"a"** and **"b",** so for this example to select input **B** to the output at **Q**, the binary input address would need to be "**a**" = logic "**1**" and "**b**" = logic "**0**".

Multiplexer Input Line Selection

Adding more control address lines will allow the multiplexer to control more inputs but each control line configuration will connect only ONE input to the output. Then the implementation of the Boolean expression above using individual logic gates would require the use of seven individual gates consisting of AND, OR and NOT gates as shown.

4 Channel Multiplexer using Logic Gates



Multiplexers are not limited to switching a number of different input lines or channels to one

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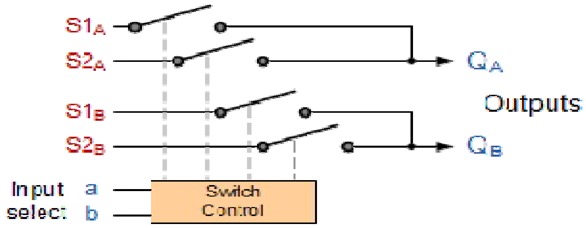
common single output.There are also types that can switch their inputs to multiple outputs and have arrangements or 4-to-2, 8-to-3 or even 16-to-4 etc configurations and an example of a simple Dual channel 4 input multiplexer (4-to-2) is given below:

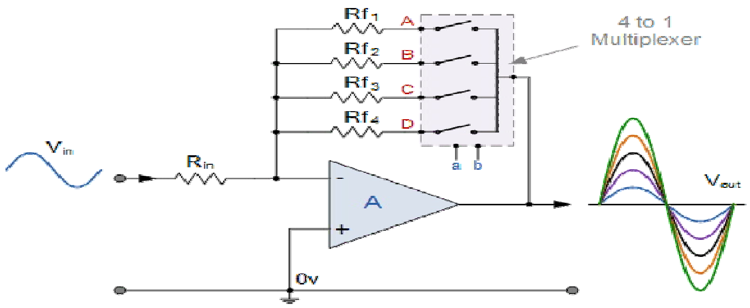
4-to-2 Channel Multiplexer

This simple 4-to-2 configuration could be used to switch audio signals for stereo pre-amplifiers or mixers.



Adjustable Amplifier Gain

As well as sending parallel data in a serial format down a single transmission line or connection, another possible use of multi-channel multiplexers is in digital audio applications as mixers or where the gain of an analogue amplifier can be controlled digitally e.g.**Digitally Adjustable Amplifier Gain**. Here, the voltage gain of the inverting operational amplifier is dependent upon the ratio between the input resistor, R_{in} and its feedback resistor, R_f as determined in the Op-amp tutorials. A single 4-channel (Quad) SPST switch configured as a 4-to-1 channel multiplexer is connected in series with the resistors to select any feedback resistor to vary the value of R_f.



The combination of these resistors will determine the overall gain of the amplifier, (Av). Then the gain of the amplifier can be adjusted digitally by simply selecting the appropriate resistor combination. Digital multiplexers are sometimes also referred to as “Data Selectors”.

Human Machine Interface

This is a user interface in a manufacturing or process control system. It provides a graphics-based visualization of an industrial control and monitoring system. A HMI typically resides in an office-based Windows computer that communicates with a specialized computer in the plant such as a programmable automation controller (PAC), programmable logic controller (PLC) or distributed control system (DCS).

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TOPIC FIVE

FUNDIMENTALS OF ROBOTS

Robots are devices that are programmed to move parts, or to do work with a tool. Robotics is a multidisciplinary engineering field dedicated to the development of autonomous devices, including manipulators and mobile vehicles.A robot can be defined as follows:

1. A robot is a re-programmable multi-functional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

2. A robot is an automatically controlled, reprogrammable, multipurpose, manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications.

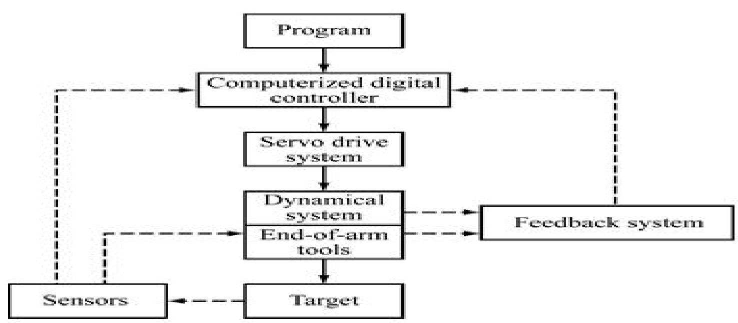
3. A robot is any automatically operated machine that replaces human effort, though it may not resemble human beings in appearance or perform functions in a humanlike manner.

4. A robot is an electric machine which has some ability to interact with physical objects and to be given electronic programming to do a specific task that may also have some ability to perceive and absorb data on physical objects or on its local physical environment, or to process data, or to respond to various stimuli.

5. A robot is a mechanical device that sometimes resembles a human and is capable of performing a variety of often complex human tasks on command or by being programmed in advance.

Basic Elements of Robotics System

The basic element of a robot includes the following:



Six Basic Elements of Robots

1. **Mechanical platform- the hardware base**
   - such as a wheeled platform, arm, or other construction, capable of interacting with its environment.

2. Sensors

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- Sensors are the parts that sense and can detect objects or things like heat and light and convert the object information into symbols or in analog or digital form and then robot reacts according to the information provided by the sensory system. The sensors used in robotics are;

 Vision Sensors: Camera, Frame Grabber, Image processing unit

 Proximity Sensors: distance is estimated between the robot and the object.

 Proprioceptive Sensors: are responsible for monitoring self-maintenance and controlling internal status. This includes battery monitoring, current sensing, and heat monitoring.

 Logical Sensors

2. *Motors*

A variety of electric motors provide power to robots making them move with various programmed motions. AC /DC motors can be used.

3. *Driving Mechanisms*:

Gears and Chains, Pulleys and Belts, Gearboxes are used to transmit rotational motion from one place to another

4. *Servomotors*

They adjust themselves until they match the signal. A very common use of servos is in Radio Controlled models (R/C Servos).

5. ***Power Supply:*** Power supply is provided by two types of sources:

 Batteries that are used once only and then discarded.

 Rechargeable batteries: operate from a reversible chemical reaction and can be recharged thousand times.

6. *Electronic controls:*

This uses a digital logic control circuit which controls the mechanical system. This circuit is connected to the mechanical system through a bridge relay. A control signal generates a magnetic field in the relay's coil that mechanically closes a switch.

7. *Microcontroller systems*

Microcontrollers are intelligent electronic devices that are used inside robots. They deliver functions similar to those performed by a microprocessor (CPU) inside a personal computer. It comprises of;

- ✓ *Speed:* is designated in clock cycles, and is usually measured in millions of cycles per second (Megahertz, MHz).
- ✓ *Size:* specifies the number of bits of information the Microcontroller can process in one step (e.g, 4-, 8-, 16-, and 32-bits).
- ✓ *Memory:* Microcontrollers count most of their **read-only memory** (ROM) in thousands of bytes (kB) and r**andom access memory** (RAM) in single bytes.

8. ***Languages***

The following programming languages are used:

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- VAL - Variable Assembly Language
- Robo ML - Robotic Mark-up Language
- ROBOFORTH
- ROSSUM
- XRCL - Extensible Robot Control Language
- Scripting language such as RoboLogics
- Visual Programming Languages is written by Labview

9. ***Pneumatics:***
Pneumatic system is used for actuating purposes. Pneumatics are useful for generating linear motion.

10. ***Driving high-current loads from logic controllers:***
- the interfacing of logic circuitry to high current loads such as motors, solenoids, or Nitinol wire. Logic circuitry can sink and source loads in the range of 1 to 20 mA. The logic circuitry are;
    - *Switch basics*: interface for high-current loads can be though of as a switch.
    - *Relays*: One of the simplest ways to accomplish high-current..
    - *Transistors:* an semiconductor version of a relay.
    - *H-Bridges:* Most loads such as motors need to be operated in both forward and reverse.

Types of robots

There are three types of robots;

i. Manual robots
ii. Semi-automatic robots
iii. Automatic robots

Classification of Robot

Robots can be classified in many ways. This is according to;

a). their degrees of freedom,
b). kinematical structure,
c). drive technology,
d). work-shop geometry and
e). motion characteristics.

[A] Classification of robots by *Degrees of Freedom*

A manipulator should have 6 degrees of freedom to manipulate an object freely in three dimensional spaces and thus from this point of view a robot may be a;

i). **General purpose robot:** if it possesses 6 degrees of freedom.
ii). **Redundant robot:** if it possesses more than 6 degrees of freedom. It provides more freedom to move around obstacles and operate in a tightly confined work space.
iii). **Deficient robot:** if it possesses less than 6 degrees of freedom.

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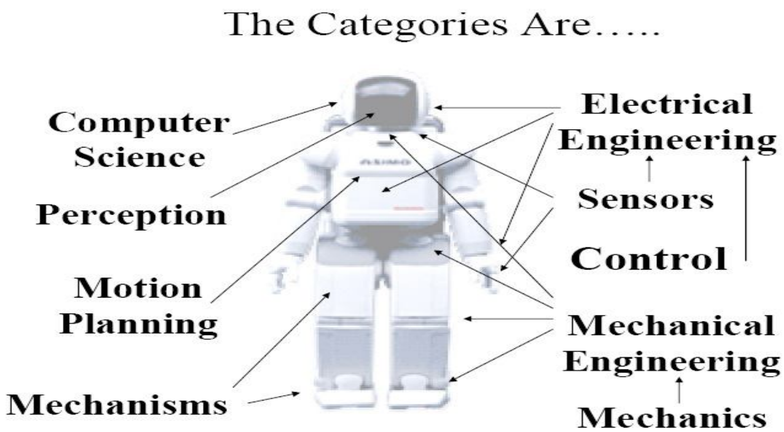

[B] Classification of robots by Kinematic Structure

According to kinematic structure robots can be classified as;

i). **Serial Robot or Open- loop Manipulator:-**A robot is said to be a serial robot or an open-loop manipulator if its kinematic structure takes the form of an open-loop chain. Example: Adept-One Robot.

ii). **Parallel Manipulator:-**if it is made up of a closed-loop chain. In general, a parallel manipulator has the advantages of higher stiffness, higher payload capacity, and lower inertia to the manipulation problem than a comparable serial manipulator, at the price of a smaller workspace and more complex mechanism

iii). **Hybrid Manipulator:-**if it consists of both open and closed loop chains. Example: Fanuc S-900 W. Many industrial robots employ this type of robot construction.

[C] Classification of robots by Drive Technology

Manipulators can be classified by their three drive technologies are;

i). **Electric Technology:-**Most manipulators use either electric DC servomotor or stepper motors because they are clean and relatively easy to control.

ii). **Hydraulic Technology:-**used for high speed and/or high-load-carrying capabilities. A major disadvantage associated with this is the possibility of leaking oils. A hydraulic drive is inherently flexible, due to bulk modulus of oil.

iii). **Pneumatic Technology:** Also used for high speed and/or high-load-carrying capabilities. A pneumatic drive is clean and fast but it is difficult to control because air is a compressible fluid.

[D] Classification of robots by Workspace Geometry

The workspace of a manipulator can be defined as the volume of space the end of effecter can reach. The workspace can be of two types:

A *reachable workspace* is the volume of space withinwhich every point can be reached by the end effecter in at least one orientation.

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A *dexterous workspace* is the volume of space within which every point can be reached by the end effecter inall possible orientation.

i).Cartesian robot

In this the kinematic structure of a robot arm is made of three mutually perpendicular prismatic joints. The wrist center position of a Cartesian robot can be described by three Cartesian co-ordinates associated with the three prismatic joints. The regional work-space of a Cartesian robot is a rectangular box. When a Cartesian robot is mounted on rails above its workspace, it is called a **gantry robot.**

ii).Cylindrical Robot

A robot arm is called cylindrical robot if either the first or second joint of a Cartesian robot is replaced by a revolute join. The wrist center position of a cylindrical robot can be described by a set of cylindrical coordinate system associated with the three joint variables. The workspace of a cylindrical robot is confined by two concentric cylinders of finite length.

iii).Spherical Robot

A robot arm is called a spherical robot if either the first or second joint of a Cartesian robot is replaced by a revolute joint. The wrist center position of a spherical robot can be described by a set of spherical coordinate system associated with the three joint variables. The workspace of cylindrical robot is confined by two concentric spheres.

iv).Articulated Robot

A robot arm is said to be an articulated robot if all three joints are revolute. The workspace of an articulated robot is very complex, typically a crescent shaped cross section. Puma robot is an articulated robot.

v).The SCARA (selective compliance assembly robot arm) Robot:

It is a special type of robot consisting of two revolute joints followed by a prismatic joint. All three joint axes are parallel to each other and point along the direction of gravity. The wrist has one degree of freedom and the entire robot has 4 degrees of freedom. This type of robot is useful for assembling parts on a plane.

[E] Classification of robots by Motion Characteristics

Robot manipulators can also be classified according to their nature of motion as follows:

i). **Planar**

A manipulator is called a planar manipulator if its mechanism is a planar mechanism. Planar manipulators are useful for manipulating an object on a plane.

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ii). **Spherical**

A rigid body is said to be under a spherical motion if all particles in the body describe curves that lie on concentric spheres. A mechanism is said to be a spherical mechanism if all the moving links perform spherical motion about a common stationary point. A manipulator is called a spherical manipulator if it is made up of a spherical mechanism.

iii). **Spatial Manipulator**

A rigid body is said to perform a spatial motion if its motion cannot be characterized as planar or spherical motion. A manipulator is called a spatial manipulator if at least one of the moving links in the mechanism possesses a general spatial motion. Planar and spherical mechanisms can be considered as special cases of spatial mechanisms.

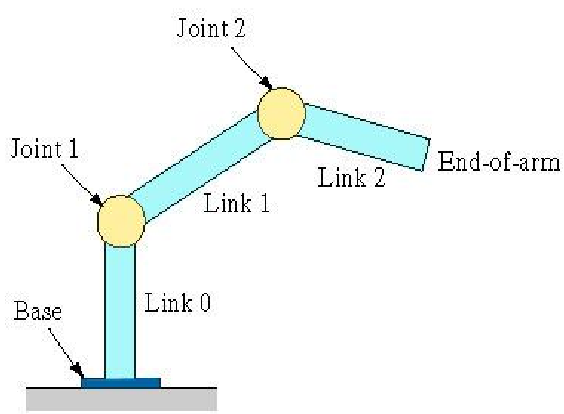
Laws of Robotics

Asimov proposed the three "Laws of Robotics" and later added a 'Zeroth law' as given below:

- **Law Zero**:
  A robot may not injure humanity, or, through inaction, allow humanity tocome to harm.
- **Law One**:
  A robot may not injure a human being, or, through inaction, allow a humanbeing to come to harm, unless this would violate a higher order law.
- **Law Two**:
  A robot must obey orders given to it by human beings, except where such orderswould conflict with a higher order law.
- **Law Three**:
  A robot must protect its own existence as long as such protection does notconflict with a higher order law.

Robot Anatomy

Industrial robots come in a variety of shapes and sizes. They are capable of various armmanipulations and they possess different motion systems.Four basic configurations are identified with available industrialrobots:



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1. Cartesian configuration

A robot which is constructed around this configuration consistsof three orthogonal slides, as three slides are parallel to the x, y, and z axesof the Cartesian coordinate system. By appropriate movements of these slides, the robot iscapable of moving its arm at any point within its three dimensional rectangular spaced workspace.

2. Cylindrical configuration

The robot body is a vertical column thatswivels about a vertical axis. The arm consists of several orthogonal slides which allow thearm to be moved up or down and in and out with respect to the body.

3. Polar configuration

This configuration also goes by the name "spherical coordinate"because the workspace within which it can move its arm is a partial sphere. The robot has a rotary base and a pivot that can be used to raise and lower atelescoping arm.

4. **Jointed-arm configuration**

It is combination of cylindrical and articulated configurations.This is similar in appearance to the human arm,the arm consists of severalstraight members connected by joints which are analogous to the human shoulder, elbow, andwrist. The robot arm is mounted to a base which can be rotated to provide the robot with thecapacity to work within a quasi-spherical space.

Basic Robot Motions

Whatever the configuration, the purpose of the robot is to perform a useful task. Toaccomplish the task, an end effector, or hand, is attached to the end of the robots arm. It is theend effector which adapts the general purpose robot to a particular task. To do the task, therobot arm must be capable of moving the end effectors through a sequence of motions andpositions.There are six basic motions or degrees of freedom, which provide the robot with thecapability to move the end effectors through the required sequences of motions. These sixdegree of freedom are intended to emulate the versatility of movement possessed by thehuman arm. Not all robots are equipped with the ability to move in all six degrees. The sixbasic motions consist of three arm and body motions and three wrist motions.

Arm and body motions

1.Vertical traverse:

-Up and down motion of the arm, caused by pivoting the entire armabout a horizontal axis or moving the arm along a vertical slide.

2. Radial traverse:

-extension and retraction of the arm (in and out movement)

3.Rotational traverse:

-rotation about the vertical axis (right or left swivel of robot of the arm)

4. Wrist Motion

• Wrist swivel: Rotation of the wrist

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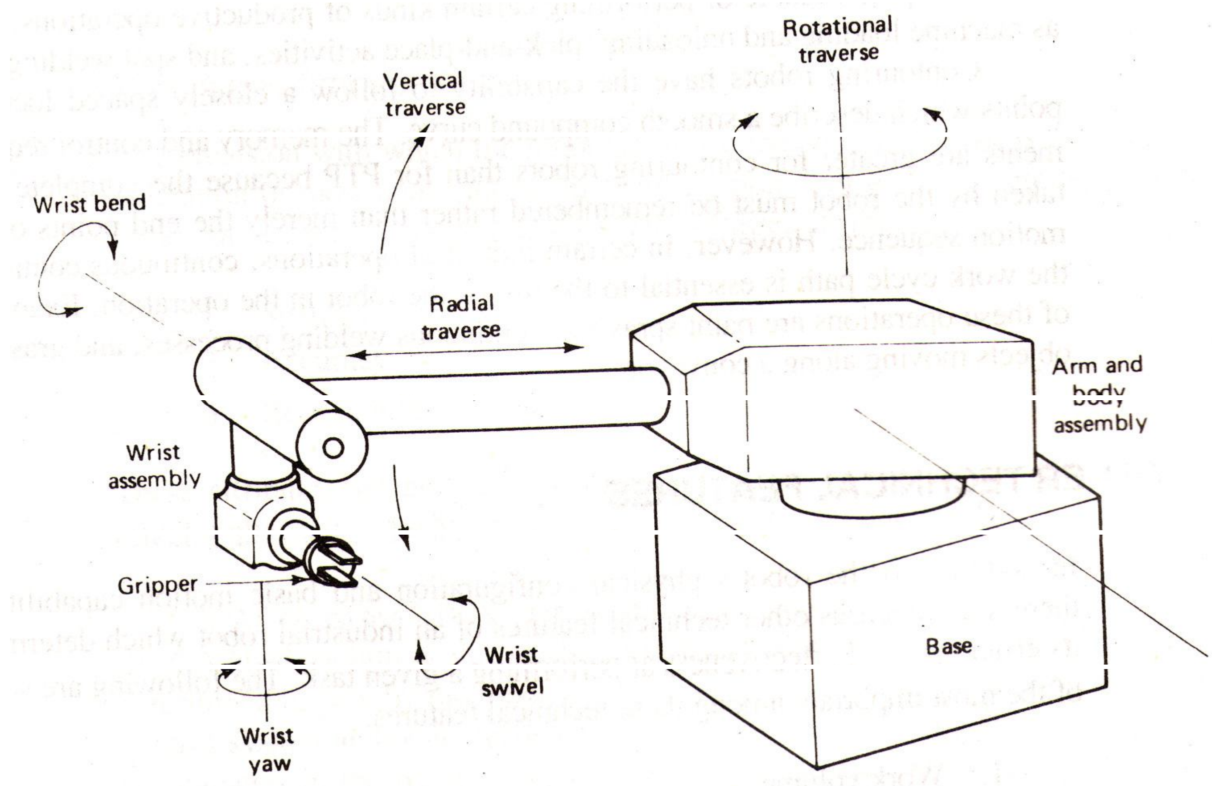
• Wrist bend: Up or down movement of the wrist, this also involves rotationmovement.
• Wrist yaw: Right or left swivel of the wrist.

Motion systems

1. **Point-to-point (PTP) control robot:** is capable of moving from one point to anotherpoint. The locations are recorded in the control memory. PTP robots do not controlthe path to get from one point to the next point. Common applications includecomponent insertion, spot welding, hole drilling, machine loading and unloading, andcrude assembly operations.
2. **Continuous-path (CP) control robot:** with CP control, the robot can stop at anyspecified point along the controlled path. All the points along the path must be storedexplicitly in the robot's control memory. Typical applications include spray painting,finishing, gluing, and arc welding operations.
3. **Controlled-path robot:** the control equipment can generate paths of differentgeometry such as straight lines, circles, and interpolated curves with a high degree ofaccuracy. All controlled-path robots have a servo capability to correct their path.



Technical Features of an Industrial Robot

The features of an industrial robot determine its efficiency and effectiveness atperforming a given task. The following are some of the most important among these technicalfeatures.

1. **Degree of Freedom (D.O.F)**

Each joint on the robot introduces a degree of freedom. Eachof can be a slider, rotary, or other type of actuator. Robots have 5 or 6 degrees offreedom: 3 of the degrees of freedom allow

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positioning in 3D space, while the other 2or 3 areused for orientation of the end effector. 6 degrees of freedom are enough to allow the robot toreach all positions and orientations in 3D space. 5 D.O.F requires a restriction to 2D space, orelse it limits orientations. 5 D.O.F robots are used for handling tools such as arcwelders.

2. **Work Volume/Workspace**

The robot tends to have a fixed and limited geometry. Thework envelope is the boundary of positions in space that the robot can reach. For a Cartesianrobot (like an overhead crane) the workspace might be a square, for more sophisticated robotsthe workspace might be a shape that looks like a ‘clump of intersecting bubbles’.

3. Precision Movement

The precision with which the robot can move the end of its wrist is a critical consideration in most applications. A portion of a linear positioning system axis, with showing control resolution, accuracy and repeatability is required. In robotics, precision of movement is a complex issue, and we willdescribe it as consisting of three attributes:

i). Control resolution
ii). Accuracy
iii). Repeatability

i. Control Resolution

This is the smallest change that can be measured by the feedbacksensors, or caused by the actuators, whichever is larger. If a rotary joint has an encoder thatmeasures every 0.01 degree of rotation and a direct drive servo motor is used to drive thejoint, with a resolution of 0.5 degrees, then the control resolution is about 0.5 degrees (theworst case can be 0.5+0.01).

ii. Accuracy

This is determined by the resolution of the workspace. If the robot is commandedto travel to a point in space, it will be off by some amount, the maximum distanceshould be considered the accuracy.

iii. Repeatability

The robot mechanism will have some natural variance in it. This means thatwhen the robot is repeatedly instructed to return to the same point, it will not always stop atthe same position.

5. **Speed**

Refers either to the maximum velocity that is achievable by the TCP, or by individualjoints. This number is not accurate in most robots, and will vary over the workspace as thegeometry of the robot changes.

6. **Weight Carrying Capacity** (Payload)

The payload indicates the maximum mass the robotcan lift before either failure of the robots, or dramatic loss of accuracy. It is possible toexceed the maximum payload, and still have the robot operate, but this is not advised. Whenthe robot is accelerating fast, the payload should be less than the maximum mass. This isaffected by the ability to firmly grip the part, the robot structure and the actuators.The end of arm tooling should be considered part of the payload.

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Key features of Robots

i. **Quality-**offer a characteristic property that defines the apparent individual nature of something or service rendered. They offer high quality services.
ii. **Serviceability**- The quality of being able to provide good service.
iii. **Safety**- The state of being certain that adverse effects will not be caused by some agent under defined conditions. It a device designed to prevent injury or accidents.
iv. **Modularity**- Constructed with standardized units or dimensions for flexibility and variety in use.
v. **Dexterity**- Skillful performance or ability without difficulty and without using hands.

Robot Drive Systems

There are three basic drive system used in available robots:

1. **Hydraulic drive:**
   They give a robot great speed and strength. These systems can be designed to actuate linear or rotational joints. The main disadvantage of a hydraulic system is that it occupies floor space in addition to that required by the robot.
2. **Electric drive:**
   An electric system provides a robot with less speed and strength and that is why electric drive systems are adopted for smaller robots and thus robots supported by electric drive systems are more accurate, exhibit better repeatability, and are cleaner to use.
3. **Pneumatic drive:**
   They are generally used for smaller robots. These robots, with fewer degrees of freedom, carry out simple pick-and-place material handling operations.

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CHAPTER 6
PROGRAMMING A ROBOT

There are various methods which robots can be programmed to perform a given work cycle and theyof four categories as follows;

1. Manual method
2. Walkthrough method
3. Lead through method
4. Off-line programming method

1. Manual method

This method is not really programming in its sense but more like setting up a machine rather than programming. It is the procedure used for the simpler robots and involves setting mechanical stops, cams, switches or relays in the robots control unit. For these low technology robots used for short work cycles (e.g., pick and place operations), the manual programming method is adequate.

2. Walkthrough method

In this method the programmer manually moves the robots arm and hand through the motion sequence of the work cycle. Each movement is recorded into memory for subsequent playback during production. The speed with which the movements are performed can be controlled independently so that the programmer does not have to worry about the cycle time during the walk through. The main concern is getting the position sequence correct. The walk through method would be appropriate for spray painting and arc welding.

3. Lead-through method

The lead-through method makes use of a teach pendant to power drive the robot through its motion sequence. The teach pendant is a small hand held device with switches and dials to control the robots physical movements. Each motion is recorded into memory for future playback during work cycle. The lead through method is very popular among robot programming methods because of its ease and convenience.

Advantages of this programming include:

_ It is easy and no special programming skills or training

Disadvantages of this programming include:

_ it is not practical for large or heavy robots
_ High accuracy and straight-line movements are difficult to achieve
_ it is difficult to *edit out* unwanted operator moves
_ it is difficult to incorporate external sensor data
_ it is difficult to synchronization with other machines or equipment in the work cell
_ A large amount of memory is required

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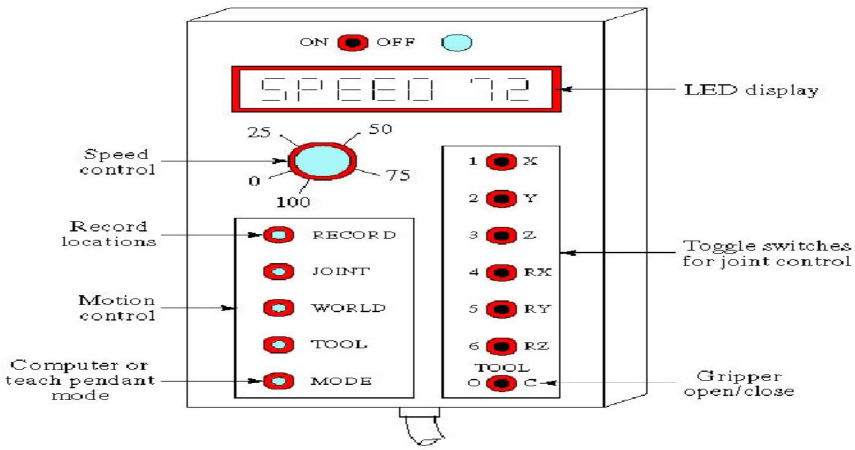

4.Off- line programming method

This method involves the preparation of the robot program off-line. Off-line robot programming is accomplished on a computer terminal. After the program has been prepared, it is entered in to the robot memory for use during the work cycle. The advantaged of off-line robot programming is that the productiontime of the robot is not lost to delay in teaching the robot a new task. Programming off-linecan be done while the robot is still in production on the preceding job. This means higher utilization of the robot and the equipment with which it operates. Another benefit associated with off-line programming is the prospect of integrating the robot into the factory CAD/CAM data base and information system.

Robot Programming Languages

Non-computer controlled robots do not require programming language. They are programmed by the walkthrough or lead through methods while the simpler robots are programmed by manual methods. With the introduction of computer control for robots, came the opportunity and the need to develop a computer oriented robot programming language that include;

1. **The VALTM Language**

   • The VAL language was developed for PUMA robot

   • VAL stands for Victors Assembly Language

   • It is an off-line language in which program defining the motion sequence.

   • VAL statements are divided into two categories;

   a) Monitoring command

   b) Programming instructions.

   • Monitor command are set of administrative instructions that direct the operation of the robot system.

   • Examples for monitor commands are: EDIT, EXECUTE, SPEED, HERE etc.

   • Program instructions are a set of statements used to write robot programs. One statement usually corresponds to one movement of the robots arm or wrist.

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• Example for program instructions are :- Move to point, Move to a point in a straight line motion, open gripper, close gripper. (MOVE, MOVES, APPRO, APPROS, DEPART, OPENI, CLOSEI, AND EXIT).

2. **The MCL Language**

• MCL stands for Machine Control Language developed by Douglas.

• The language is based on the APT and NC language.

• MCL is enhancement of APT which possesses additional options and features needed to do off-line programming of robotic work cell.

• Provides the supplementary capabilities intended to be covered by the MCL. These capability include Vision, Inspection and Control of signals

• MCL permits the user to define MACROS like statement that would be convenient to use for specialized applications.

• MCL program is needed to compile to produce CLFILE.

• Some commands of MCL programming languages are DEVICE, SEND, RECEIV, WORKPT, ABORT, TASK, REGION, LOCATE etc.

Textual Statements

Language statements include basic motion statement lke:

MOVE P1

Commands the robot to move from its current position to a position and orientation defined by the variable name P1.The point p1 must be defined. The most convenient method way to define P1 is to use either powered lead through or manual leads through to place the robot at the desired point and record that point into the memory.

HERE P1 OR LEARN P1

These are used in the lead through procedure to indicate the variable name for the point. What is recorded into the robot's control memory is the set of joint positions or coordinates used by the controller to define the point. For example, (236,157,63,0,0,0). The first values give joint positions of the body and arm and the last three values (0,0,0) define the wrist joint positions.

MOVES P1

It denotes movement that is to be made using straight line interpolation. The suffix's' designates a straight line motion.

DMOVE (4,125)

Suppose the robot is presently at a point defined by joint coordinates (236,157,63,0,0,0) and it is desired to move joint 4from 0 to 125. DMOVE represents a delta move. Approach and depart statements are useful in material handling operations.

APPROACH P1, 40 MM; MOVE P1

Command to actuate the gripper.

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DEPART 40 MM

The destination is point p1 but the approach command moves the gripper to a safe distance(40mm) above the point. Move statement permits the gripper to be moved directly to the part for grasping. A path in a robot program is a series of points connected together in a single move. A move statement is used to drive the robot through the path. A path is given a variable name;

DEFINE PATH123=PATH (P1,P2,P3)

MOVE PATH123

SPEED 75 the manipulator should operate at 75% of the initially commanded velocity where the initial speed is given in a command that precedes the execution of the robot program. For example,

SPEED 0.5 MPS

EXECUTE PROGRAM1

This indicates that the program named PROGRAM1 is to be executed by the robot at a speed of 0.5m/sec.

Interlock and Sensor Statements

The two basic interlock commands used for industrial robots are WAIT and SIGNAL. The wait command is used to implement an input interlock. For example,

WAIT 20,ON

This would cause program execution to stop at this statement until the input signal coming into the robot controller at port 20 was in “ON” condition. This might be used in a situation where the robot needed to wait for the completion of an automatic machine cycle in a loading and unloading application. The SIGNAL statement is used to implement an output interlock. This is used to communicate to some external piece of equipment. For example,

SIGNAL 20, ON

The above interlock commands represent situations where the execution of the statement appears. There are other situations where it is desirable for an external device to be continuously monitored for any change that might occur in the device. For example, in safety monitoring where a sensor is setup to detect the presence of humans who might wander into the robot’s work volume, the sensor reacts to the presence of humans by signaling the robot controller.

REACT 25, SAFESTOP

This command would be written to continuously monitor input port 25 for any changes in the incoming signal. If and when a change in the signal occurs, regular program execution isinterrupted and the control is transferred to a subroutine called SAFESTOP. This subroutine would stop the robot from further motion and/or cause some other safety action to be taken.

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Commands for controlling the end-effectors .Although end effectors are attached to the wrist of the manipulator, they are very much like external devices. A Special command is written for controlling the end effector. Basic commands are;

OPEN (fully open)

and

CLOSE (fully close)

For grippers with force sensors that can be regulated through the robot controller, a command such as ,

CLOSE 2.0 N

This controls the closing of the gripper until a 20.N force is encountered by the grippers. A similar command would be used to close the gripper to a given opening width is,

CLOSE 25 MM

A special set of statements is often required to control the operation of tool type end effectors.(such as spot welding guns, arc welding tools, spray painting guns and powered spindles).

End Effectors

An End effector can be defined as a device which is attached to the robot's wrist to perform a specific task. The task might be work part handling, spot welding, spray painting, or any of a great variety of other functions. The possibilities are limited only by the imagination and ingenuity of the application engineers who design robot systems. The end effectors are the special purpose tooling which enables the robot to perform a particular job. For purpose organization, we will divide the various types of end effectors into two categories: grippers and tools.

1. **Grippers:**

- These are used to grasp and hold an object and place it at a desired location. Grippers can be classified as;
  - Mechanical grippers
  - Vacuum or suction cups
  - Magnetic grippers
  - Adhesive grippers
  - Hooks, Scoops, and so forth.

2. **Tools:**

- A robot is required to manipulate a tool to perform an operation on a work part. Here the tool acts as end-effectors. Spot-welding tools, arc-welding tools, spray painting nozzles, and rotating spindles for drilling and grinding are typical examples of tools used as end-effectors.

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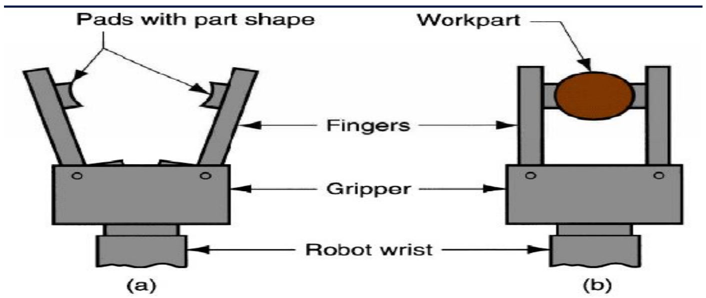

Work Cell Control and Interlocks

1. **Work cell control**

Industrial robots work with other things: processing equipment, work parts, conveyors, tools and perhaps human operators. A means must be provided for coordinating all of the activities which are going on within the robot workstations. Some of the activities occur sequentially, while others take place simultaneously to make certain that the various activities are coordinated and occur in the proper sequence, a device called the **work cell** controller is used. The work cell controller resides within the robots and has overall responsibility for regulating the activities of the work cell components. Functions of work cell controller include the following;

1. Controlling the sequence of activities in the work cycles
2. Controlling simultaneous activities
3. Making decisions to proceed based on incoming signals
4. Making logical decisions
5. Performing computations
6. Dealing with exceptional events
7. Performing irregular cycles, such as periodically changing tools

2. **Interlocks**

An interlock is the feature of work cell control which prevents the work cycle sequence from continuing until a certain conditions or set of conditions has been satisfied. In a robotic work cell, they are two types: outgoing and incoming. The outer going interlock is a signal sent from the workstation controller to some external machine or device that will cause it to operate or not to operate for example this would be used to prevent a machine from initiating its process until it was commanded to process by the work cell controller, an incoming interlock is a single from some external machine or device to the work controller which determines whether or not the programmed work cycle sequence will proceed.

Robotic Sensors

The robot must take on more human like senses and capabilities in order to perform the task in a satisfactory way. These senses and capability includes vision and hand eye coordination, touch, and hearing. The types of sensors used in robotics are grouped into three categories;

1. Vision sensors

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2. Tactile and proximity sensors
3. Voice sensors

1. Vision sensors

Robot vision is made possible by means of video camera a sufficient light source and a computer programmed to process image data. The camera is mounted either on the robot or in a fixed position above the robot so that its field of vision includes the robots work volume. The computer software enables the vision system to sense the presence of an object and its position and orientation. Vision capability would enable the robot to carry out the following kinds of operations.

- Retrieve parts which are randomly oriented on a conveyor.
- Recognize particular parts which are intermixed with other objects.
- Perform assembly operations which require alignment.

2. Tactile and proximity sensor

Tactile sensors provide the robot with the capability to respond to contact forces between itself and other objects within its work volume. Tactile sensors can be divided into two types:

a). Touch sensors

Touch sensors are used simply to indicate whether contact has been made with an object. A simple micro switch can serve the purpose of a touch sensor.

b). Stress sensors

Stress sensors are used to measure the magnitude of the contact force. Strain gauge devices are typically employed in force measuring sensors.

3. Proximity sensors

Proximity sensors are used to sense when one object is close to another object. On a robot, the proximity sensors would be located n or near the end effectors. This sensing capability can be engineered by means of optical proximity devices, eddy-current proximity detectors, magnetic field sensors, or other devices. In robotics, proximity sensors might be used to indicate the presence or absence of a work part or other object.

4. Voice sensors

Voice programming can be defined as the oral communication of commands to the robot or other machine. The robot controller is equipped with a speech recognition system which analyzes the voice input and compares it with a set of stored word patterns. When a match is found between the input and the stored vocabulary word the robot performs some actions which correspond to the word. Voice sensors could be useful in robot programming to speed up the programming procedure.

Robot Applications

There is a need to replace human labour by robots in:

• Work environment hazardous for human beings

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- Repetitive tasks, Boring and unpleasant tasks
- Multi shift operations, Infrequent changeovers
- Performing at a steady pace
- Operating for long hours without rest
- Responding in automated operations
- Minimizing variation

Industrial Robot Applications can be divided into:

a). Material-handling applications:

- Involve the movement of material or parts from one location to another.
- It includes part placement, palletizing and/or depalletizing, machine loading and unloading. This category includes the following:

1. Part Placement
2. Palletizing and/or depalletizing
3. Machine loading and/or unloading
4. Stacking and insertion operations

1. Part Placement:

- The basic operation in this category is the relatively simple pick-and-place operation.
- This application needs a low-technology robot of the cylindrical coordinate type.
- Only two, three, or four joints are required for most of the applications.
- Pneumatically powered robots are often utilized.

2. Palletizing and/or Depalletizing:

- The applications require robot to stack parts one on top of the other, that is to palletize them, or to unstack parts by removing from the top one by one, that is depalletize them.
- Example: process of taking parts from the assembly line and stacking them on a pallet or vice versa.

3. Machine loading and/or unloading:

- Robot transfers parts into and/or from a production machine.
- There are three possible cases example: bin picking, die casting and plastic molding:

_ Machine loading in which the robot loads parts into a production machine, but the parts are unloaded by some other means.

Example: a press working operation, where the robot feeds sheet blanks into the press, but the finished parts drop out of the press by gravity.

_ Machine loading in which the raw materials are fed into the machine without robot assistance. The robot unloads the part from the machine assisted by vision or no vision.

_ Machine loading and unloading that involves both loading and unloading of the work parts by the robot. The robot loads a raw work part into the process ad unloads a finished part. Example: Machine operation difficulties

- Difference in cycle time between the robot and the production machine. The cycle time of the machine may be relatively long compared to the robot's cycle time.

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4. **Stacking and insertion operation:**

• In the stacking process the robot places flat parts on top of each other, where the vertical location of the drop-off position is continuously changing with cycle time.

• In the insertion process robot inserts parts into the compartments of a divided carton. The robot must have following features to facilitate material handling:

- The manipulator must be able to lift the parts safely.
- The robot must have the reach needed.
- The robot must have cylindrical coordinate type.
- The robot's controller must have a large enough memory to store all the programmed points so that the robot can move from one location to another.
- The robot must have the speed for meeting the transfer cycle of the operation.

b). Processing Operations:

• Requires the robot to manipulate a special process tool as the end effectors.

• The application include spot welding, arc welding, riveting, spray painting, machining, metal cutting, debarring, polishing.

• Robot performs a processing procedure on the part.

• The robot is equipped with some type of process tooling as its end effector.

• Manipulates the tooling relative to the working part during the cycle.

• Industrial robot applications in the processing operations include:

_ Spot welding and Continuous arc welding

_ Spray painting

_ Metal cutting and deburring operations

_ Various machining operations like drilling, grinding, laser and water jet cutting, and riveting.

_ Rotating and spindle operations

_ Adhesives and sealant dispensing

c). Assembly Applications:

• Involve part-handling manipulations of a special tools and other automatic tasks and operations.

• The applications involve both material-handling and the manipulation of a tool.

• They typically include components to build the product and to perform material handling operations.

• Are traditionally labor-intensive activities in industry and are highly repetitive and boring. Hence are logical candidates for robotic applications.

• These are classified as:

_ Batch assembly: As many as one million products might be assembled.

_ The assembly operation has long production runs.

_ Low-volume: In this a sample run of ten thousand or less products might be made.

_ The assembly robot cell should be a modular cell.

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d). Inspection Operations:

• Require the robot to position a work part to an inspection device.

• Involve the robot to manipulate a device or sensor to perform the inspection.

• Some inspection operation requires parts to be manipulated, and other applications require that an inspection tool be manipulated.

• Inspection work requires high precision and patience, and human judgment is often needed to determine whether a product is within quality specifications or not.

• The robot may be in active or passive role.

_ In active role robot is responsible for determining the part is good or bad.

_ In the passive role the robot feeds a gauging station with the part.

Advantages of Robots

• Robotics and automation can increase productivity, safety, efficiency, quality, and consistency of Products

• Robots can work in hazardous environments

• Robots need no environmental comfort

• Robots work continuously without any humanity needs and illnesses

• Robots have repeatable precision at all times

• Robots can be more accurate than humans at milli or micro inch accuracy.

• Robots and their sensors can have capabilities beyond that of humans.

• Robots can process multiple stimuli or tasks simultaneously, humans can only one.

• Robots replace human workers who can create economic problems.

Disadvantages of Robots

• Robots lack capability to respond in emergencies, this can cause:

_ Inappropriate and wrong responses

_ A lack of decision-making power

_ A loss of power

_ Damage to the robot and other devices

_ Human injuries

• Robots may have limited capabilities in;

_ Degrees of Freedom

_ Dexterity

_ Sensors

_ Vision systems

_ Real-time Response

• Robots are costly, due to;

_ Initial cost of equipment and Installation Costs

_ Need for peripheralsand Need for training

_ Need for Programming

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END