V - UNIT

SMART SENSORS

Introduction :-

A sensor producing an electrical output when combined with interface electronic circuit's. is said to be an intelligent sensor.

→ If the interfacing circuit can perform. (a) Ranging
(b) Calibration and
(c) decision making for communication and utilization of data.

→ Both sensors and actuators are used as intelligent components of instrumentation system.

→ The block diagram of one such intelligent equipment is shown in figure.

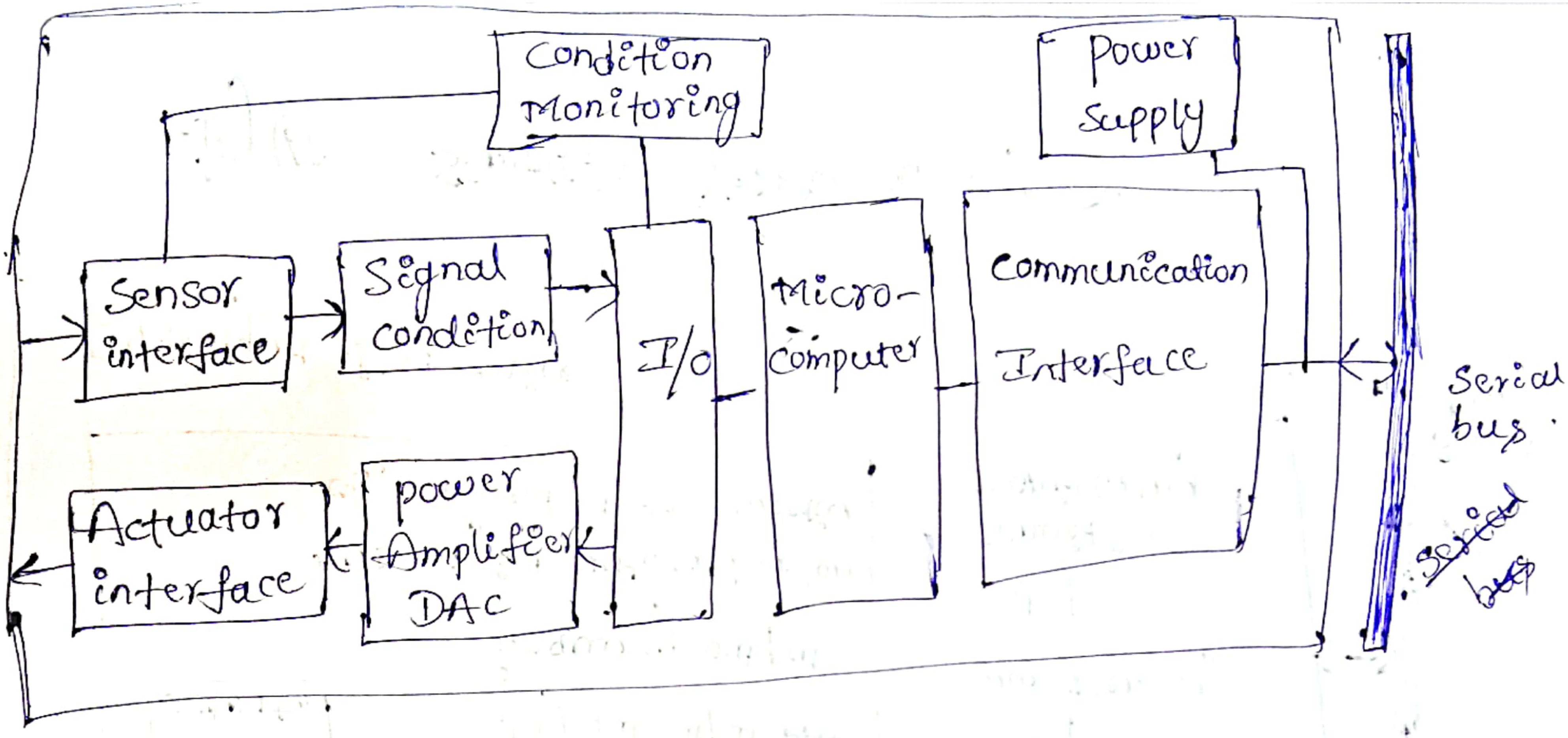

fig ⓐ Typical intelligent sensor and actuator

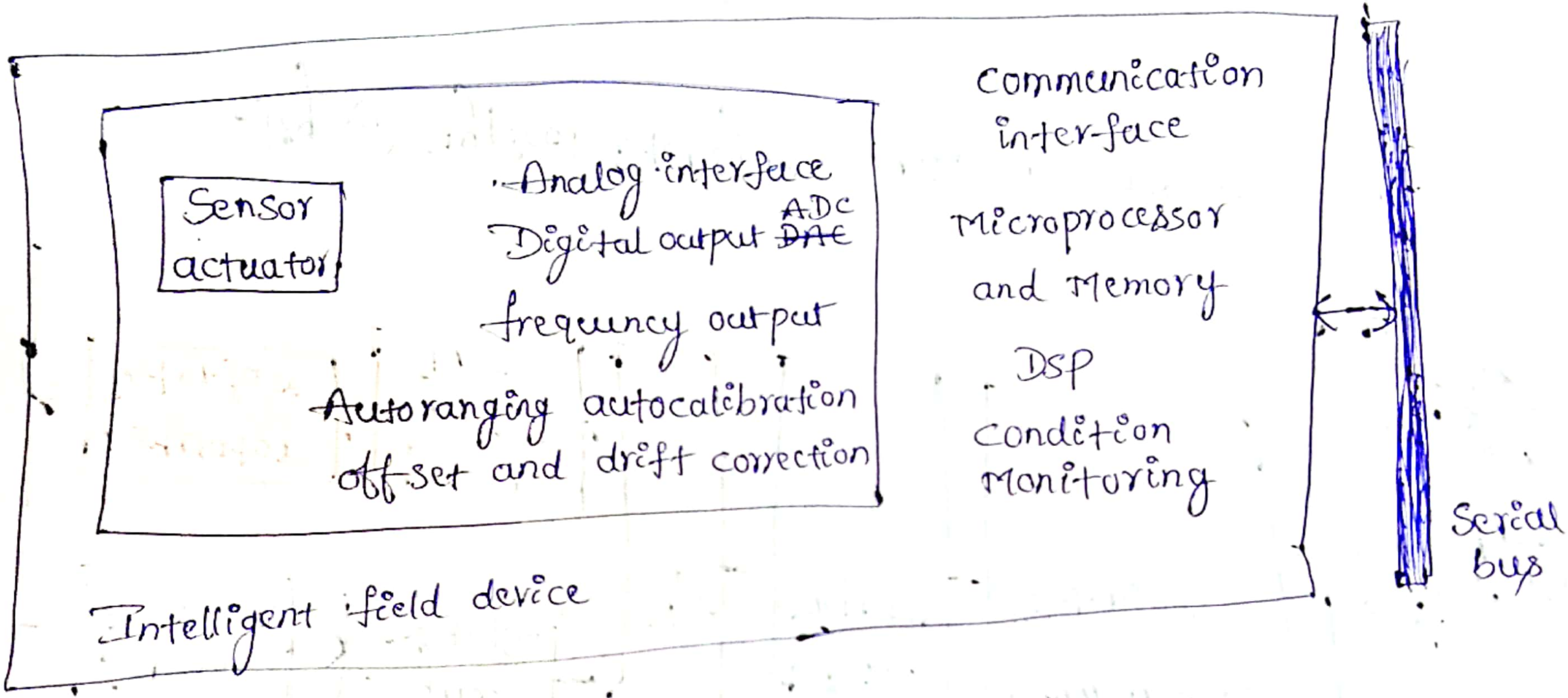

fig (b) Simplified Version of fig (a).

→ The fig ⓐ & fig ⓑ shows the simplified version with facilities of processing that can be incorporated.

⇒ An intelligent field device processes the following properties.

1. Automatic ranging and calibration through a built-in digital system.

2. Auto acquisition and storage of calibration constants in local memory of the field device.

3. Auto configuration and verification of hardware for correct operation following internal checks.

4. Auto correction of offsets, time and temperature drifts.

5. Autolinearization of Non linear transfer characteristics.

6. Self tuning control algorithms, fuzzy logic control is being increasingly used now.

7. Control programme may be locally stored or downloaded from a host system and dynamic reconfiguration performed.

8. Control is implementable through Signal bus and a host system.

9. Condition Monitoring is also used for fault diagnosis which, in turn, may involve additional Sensors, digital signal processing, and data analysis software, and.

10. Communication through a serial bus.

→ Advanced processing technologies have now replaced earlier ones used for developments of Smart sensors.

→ Sensors elements are open to process although they are now being built in the smart system itself.

→ These three systems, namely the supply amplification, and filters. comprise the analog signal processing unit (ASPU).

- Smart sensor also requires a data conversion module either from analog to digital (A/D). or frequency to digital (F/D)

- which interface with ~~mi~~ the microprocessors for information processing and bus interfacing for communication.

- figure shows a stack-block simplified version of the scheme.

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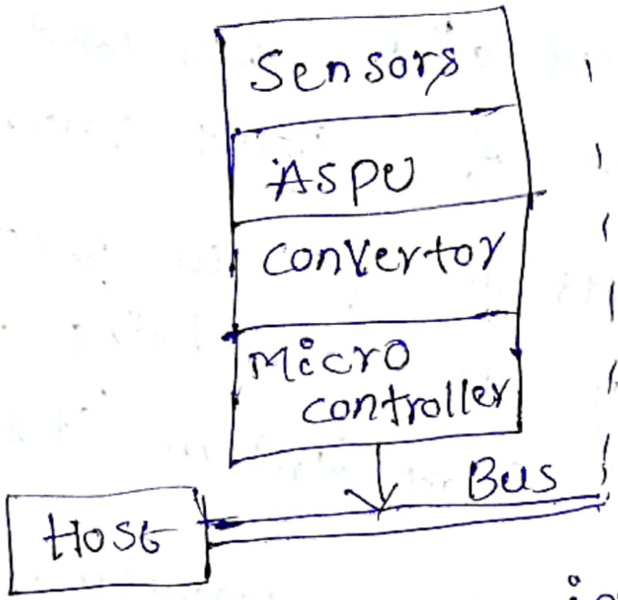


fig :- A sensor interfaced with a host system.

Primary sensors :-

→ Existing sensors of all kinds with a cascaded block for providing electrical output in the form of voltage or current can be adapted to an integrated processing system. but the system can then be hardly called a smart sensor.

→ External stimuli such as strain/stress, thermal/optical agitation, and electric / magnetic field change the behaviour of materials at ~~at~~ ~~aut~~ atomic / molecular level or in crystalline state.

→ for reliable operation of a sensor environmental conditions have to be maintained where parasitic effects do exist through limited.

→ Since electrical / electronic circuits are now largely silicon based.

→ silicon has been an element of interest for primary sensing elements.

→ Silicon based designs of some

→ silicon thermosensors and chemical sensors have also been produced.

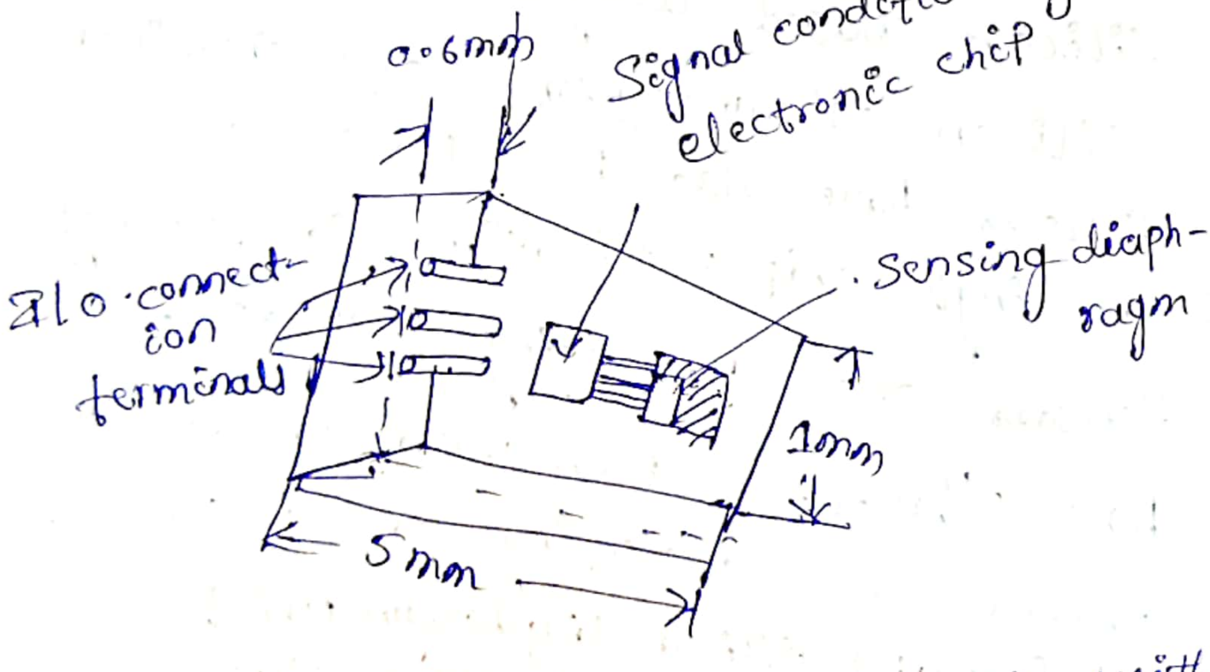
→ A single chip realization of primary sensors and processing elements has therefore been advanced to the extent of developing smart sensors.

→ deformable silicon diaphragm with piezoresistors arranged along the edges of the diaphragm.

→ Silicon based microsensor technology has been of great use in the vivo adaptation of Various types of sensors.

→ pressure sensor is an example at hand.

→ A single chip pressure sensor with signal condition unit may look like the one shown in figure.



① fig :- single chip - pressure sensor with signal conditioning units.

→ Thermal sensors based on thermo emf or seeback effect in the form of thermopiles have also been made in ICs.

→ They are batch fabricated with addition of on chip signal conditioning electronics.

→ Two semiconductors are coupled together with a difference of temperature ΔT between the junctions,

→ The open circuit emf ΔV is given by the relation. fig 2.

$$\Delta V = \alpha_s \Delta T$$

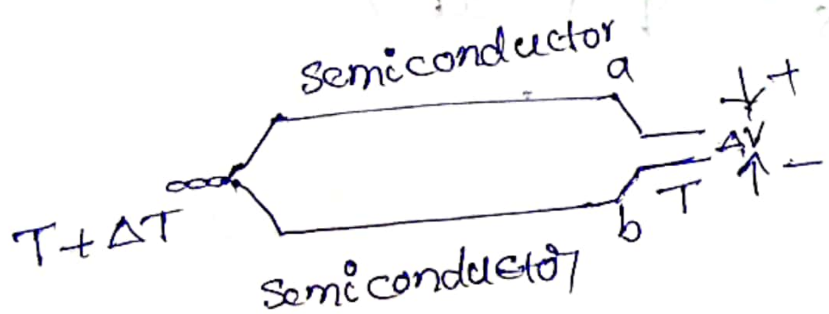


fig 2 :- Semiconductor thermo emf elements.

where α_S is the Seebeck coefficient.

If E_f is the fermi energy so that with charge q, the electrochemical potential ϕ_f is given by

$$\phi_f = \frac{E_f}{q}$$

and hence, for known E_f, α_S for silicon is obtained as

$$\alpha_S = \frac{1}{q}\left(\frac{dE_f}{dT}\right)$$

Excitation :-

Excitation is a generalized term used for supply to the primary sensors.

- When necessary this also means the supply for the entire chip including the processing units.
- This supply may be required to provide different output to different stages of the system.
- In the thermocouple form of sensors.
- An extremely stable supply is required.
- In stages of electronic processing units.
- As per requirements the facilities are to be made available for the entire chip to be self sufficient.

Amplification :-

- Considering the output of the Sensor to be generally Small.
- Amplification is essential in all Smart Sensor.
- If the gain requirement is very high, noise become a problem.
- The design and layout being critical as well.

Filters :-

Analog filters are often resorted to although filters are necessary at conversion stages, mainly because the digital type, consume large real time processing power.

Converters :-

→ Conversion is the stage of internal interfacing between the continuous and the discrete processing units.

→ The conversion, in most of the situations, does not have one to one correspondence.

→ Often controlled conversion through Software is provided with range selection and so on.

→ Data conversion from analog amplitude to frequency is often done for convenience of signal transmission.

→ The voltage controlled oscillators are used for this purpose.

- one such converter is a multivibrator shown in fig.

→ Analysis shows that the time period of the generated square wave is given by.

$T = 2RC \ln\left(1 + 2\frac{R_2}{R_1}\right)$

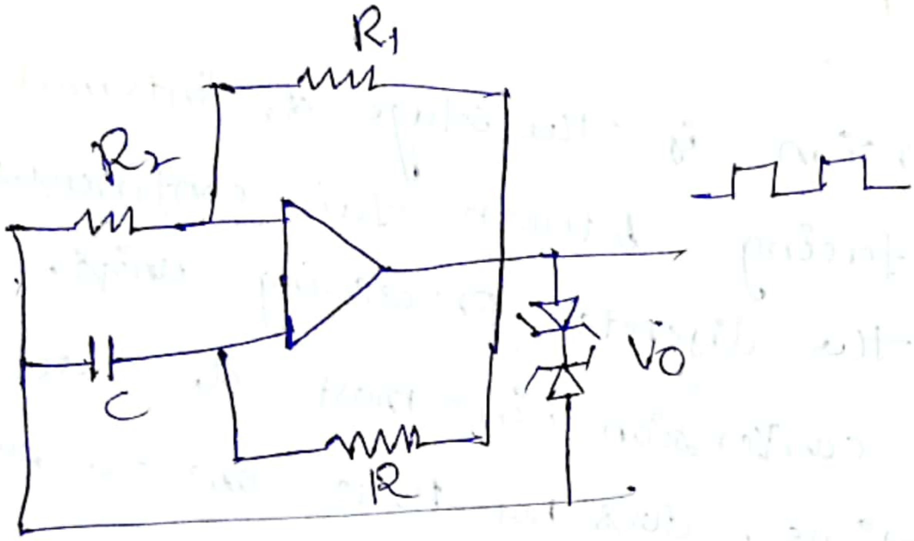


fig:- Multivibrator.

The parameter R and c can be related to the input voltage.

fixing R_2/R_1

~~T is obtained~~ as or frequency
f is ~~given~~ by $T = 2RC$

$f = \frac{1}{2RC}$

T is obtained as $T = 2RC$

frequency f is given by

$$f = \frac{1}{2RC}$$

Compensation :-

compensation is an attempt to counter all sorts of nonideality in the primary sensor characteristics as well as environment of measurement. The commonly encountered sensor defects are:

(a) non linearity
(b) noise
(c) response time
(d) drift
(e) cross sensitivity and
(f) interference.

Manufacturing tolerance may be combined under drift where as temperature and /or other environmental effects are accommodated in noise.

Nonlinearity :-

Analog processing shows serious nonlinearity which at one time, was solved by piecewise linear segment approach modelled by linear electronic circuit.

→ with digital processing methods in use. now, more readily available general techniques are there to be used for the purpose.

→ one very common technique is to look up tables. while others are polygon interpolation, polynomial interpolation, and cubic splines interpolation techniques of curve fiting.

(a) Look up table method :-

→ The sensor characteristic is described by a ~~m~~ number of reference points very close to each other which are stored in ROM with linearized values.

→ Response of the sensor for a measured value is refered to the ROM to look up for the corresponding linearized value. which is then passed on for display or further processing.

(b) Polygon interpolation :-

This method assumes that the nonlinear range is divided into a few linear sections and hence; a fewer reference points serve the purpose of linearization since between these stored reference points.

→ for hard nonlinearity, the technique fails because the reference points are numerous.

fig shows the technique of polygon interpolation.

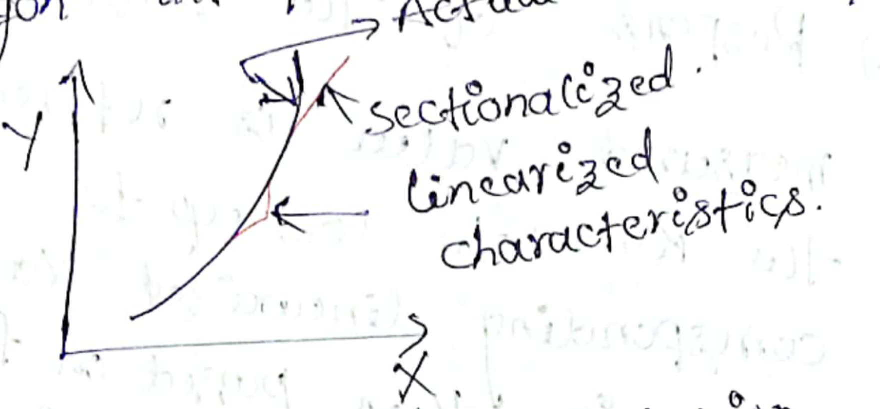


fig :- polygon interpolation.

(c) polynomial interpolation :-

→ This technique is again a standard technique which is based on the functional relationship between 'n' selected measured points on the sensor characteristics and a polynomial of order $\le (n-1)$ over the range covering the characteristics.

→ ~~Lag~~ Lagrange's interpolation ~~technique~~ technique is a very common such technique.

→ The curve is represented by the formula:

$$Y = \sum_{i=0}^{m} a_i x^i$$

(d) cubic spline interpolation:-

This method is so named as the sections of the characteristics curve of the sensor between a selected pair of reference points are represented by ~~co~~ cubic spline function as.

$$S_i(x) = a_i + b_i(x - x_i) + c_i(x - x_i)^2 + d_i(x - x_i)^3$$

Noise ~~&~~ and interference :-

- Thermal noise is important in almost all sensors.
- Noise is also introduced at different stages of signal processing such as data conversion.
- analog to digital interfacing by stray effects.
- If the signal is periodic as in the case of the output of the frequency converter.
- The correlation technique improves the signal to - noise ratio by a large value.
- If the input is corrupted at any stage by noise.

Response time :-

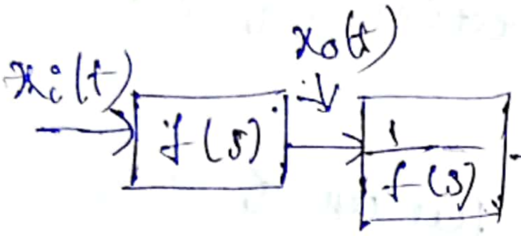
- A sensor is likely to have quite inferior time response characteristics and the 'dynamic correction' of sensor becomes necessary.
- This is possible with the use of microprocessors / microcomputers with suitable algorithm. If the dynamic parameters are known through solving the convolution integral.
- If the sensor function is given by $f(s)$, the signal processing unit should have a function $1/f(s)$ as shown in fig.

So that we obtain

$$x_i(t) = \int_0^t x_0(t-\tau)\, g(\tau)\, d\tau =$$

$$= x_0(t) * g(\tau)$$

where $g(\tau) = \mathcal{g}^{-1}\left\{\frac{1}{f(s)}\right\}$



$\rightarrow x_o(t)\, g^{-1}\left(\frac{1}{f(s)}\right)$

$= x_i(t)$

fig:- cascading complementary processing function.

the input $x_i(t)$ in terms of $x_o(t)$ is

$$x_i(t) = \frac{1}{K}\left\{x_o(t) + \left(\frac{2\xi}{\omega_0}\right)\dot{x}_o(t) + \left(\frac{1}{\omega_0^2}\right)\ddot{x}_o(t)\right\}$$

$$\ddot{x}_o(t_j) = \frac{1}{T_s}\left[\dot{x}_o(t_j) - \dot{x}_o(t_{j-1})\right]$$

Drift :-

- Drift is a kind of kind of noise and should be counteracted.
- As drift tends to change the sensor characteristics.
- The reference points for polynomial interpolation also tend to drift.

Cross Sensitivity :-

- The sensitivity for the desired measured and minimize that for the other
- A common undesired interfering variable is temperature for non-thermal sensor.
- If the interfering variable is denoted as z, output as y and measurand as x, the nominal or rated z,

The function $Y(x, z)$ can be expressed as a series of the base characteristics $Y_0(x, z_0)$ given by

$$y(x, z) = \alpha_0(z) + [1 + \alpha_1(z)] y_0(x, z_0)$$
$$+ \alpha_2(z) y_0^2(x, z_0) + \cdots$$

Information coding / Processing :-

Information : the state of the process in the form of a processed signal through sensor and signal processing systems.

- The signals are coded and displayed over appropriate display modules as is done in digital meters, indicators, recorders.

- A typical IC temperature sensor-based smart sensor is depicted in figure.

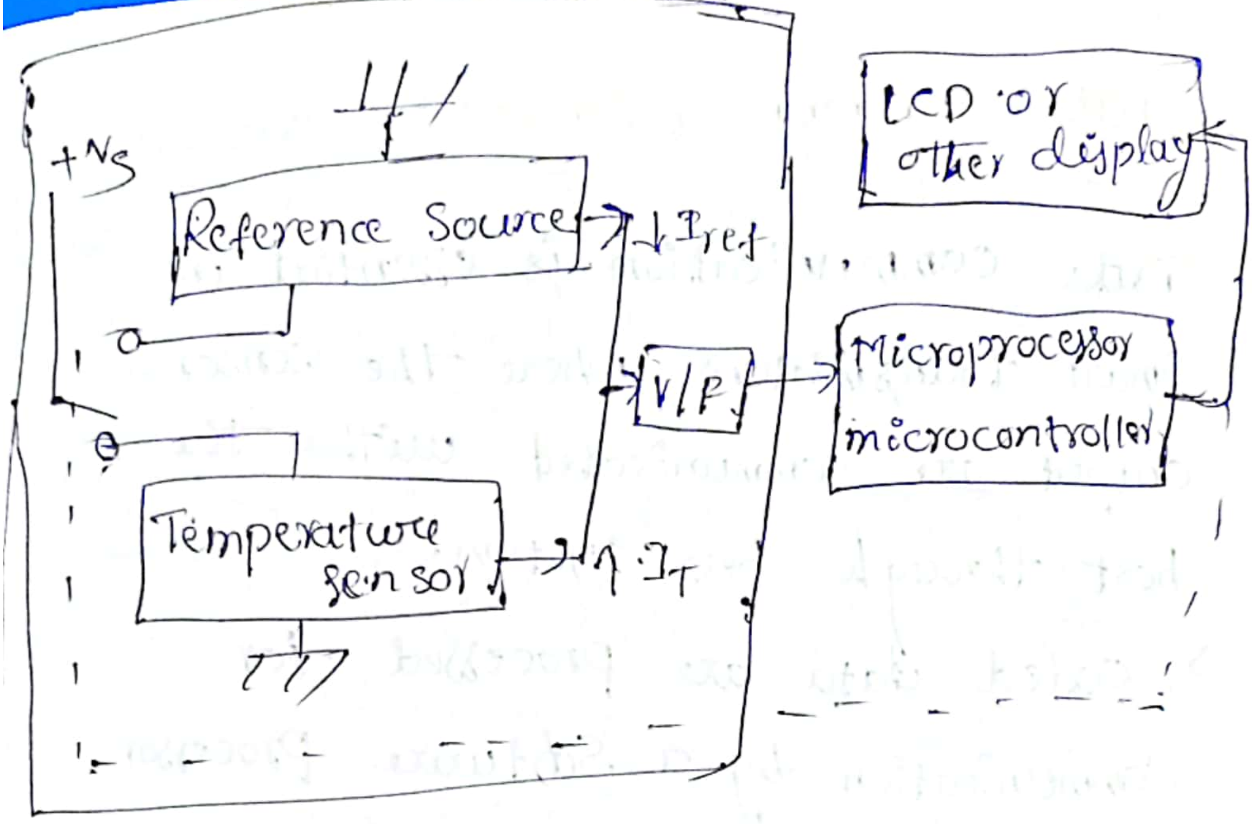


fig:- A typical IC-temperature based smart sensor

In addition to display, control system should be able to read the signals for their functioning.

- Information processing assembly in a smart sensor is basically an encoder.
- The conventional signal processing provides an output of 4-20mA.
- voltage-to-frequency converter is another kind which is quite extensively used. then using a reference frequency generator.

Data communication :-

- Data communication is essential in Smart transmitters where the sensor output are communicated with the host through bus system.
- Coded data are processed for Communication by a Software processor and a suitable interface system communicates between the processor and the bus.
- The bus was, till lately, being standardized.
- Each Smart sensor/transmitter has always been provided with a local operating system in a ROM.
- That consists of an applications Programme and library modules, for ADC and DAC hardwares, bus driving hardware, local interface

hardware, and LCD/keyboard hardware.

→ An international standard in protocols has been reached which permits any host to be in communication with the smart sensor/transmitter system.

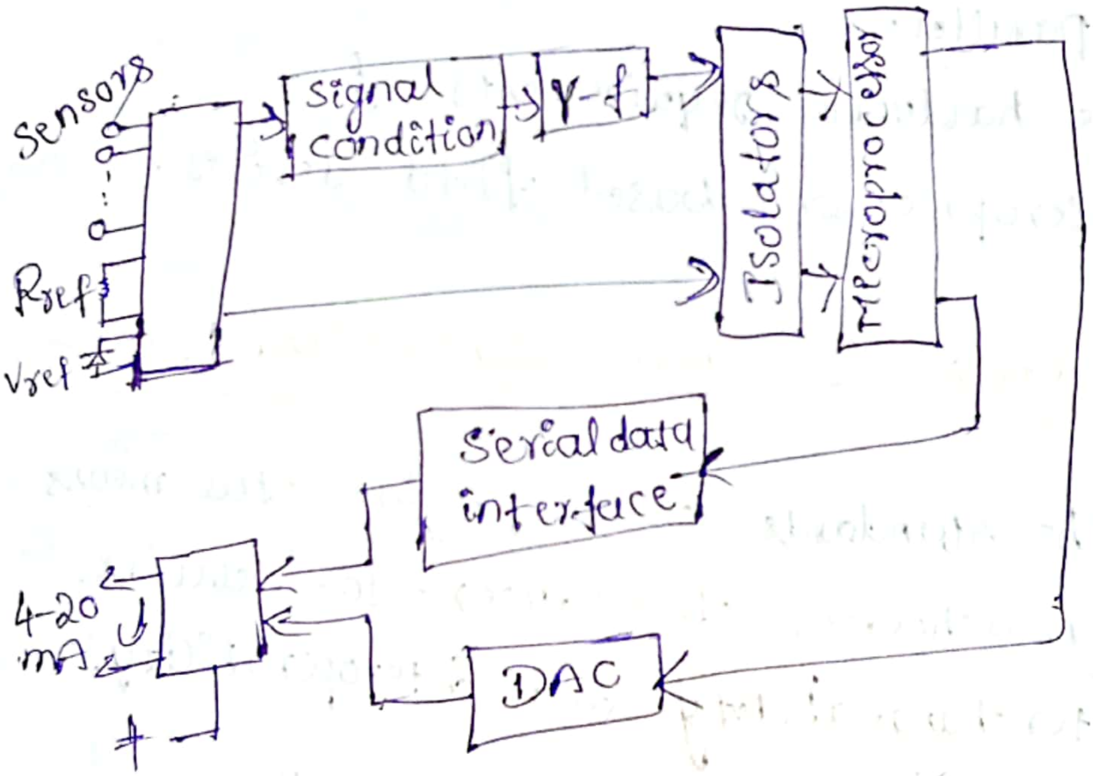


fig:- A smart transmitter

- A digital transmission protocol on the standard 4-20 mA loop.
- A typical transmitter with HART protocol appears as the one shown in figure.

→ The HART protocol has been designed for direct use of 4-20 mA output device having facilities of digital communication with superimposed modulation between the field device and a host system.

→ Such devices can be connected in parallel.

→ The hardware requirements for microprocessor - based field devices.

Standards for Smart Sensor Interface:-

→ The standards is to provide the means for achieving transducer-to-network interchangeability and interoperability.

→ To define a set of common communication interfaces for connecting transducers to microprocessor-based systems, instruments, and field network in a network-independent environment.

→ figure shows a scheme of communication using IEEE.

→ NCAP - Network capable Application processor.

→ such an object model provides two interfaces

→ (i) To the model - this resembles an I/O driver.

→ (ii) to The NCAP block and ports with details of different network protocol schemes. this is implementation IEEE P. 1451.1

→ The IEEE 1451.2 provides the transducer to microprocessor communication protocols and transducer electric data sheet formats.

- It also provides the digital interface and communication protocols between the transducers and microprocessors.

→ IEEE P 1451.3 provides digital communication and TEDS formats for distributed multiloop systems.

→ IEEE P 1451.4 provides mixed mode communication protocols and also the TEDS formats.

- This is intended to develop bidirectional communication of digital TEDS in addition to an interface for mixed mode transducers.

~~The Automation:-~~

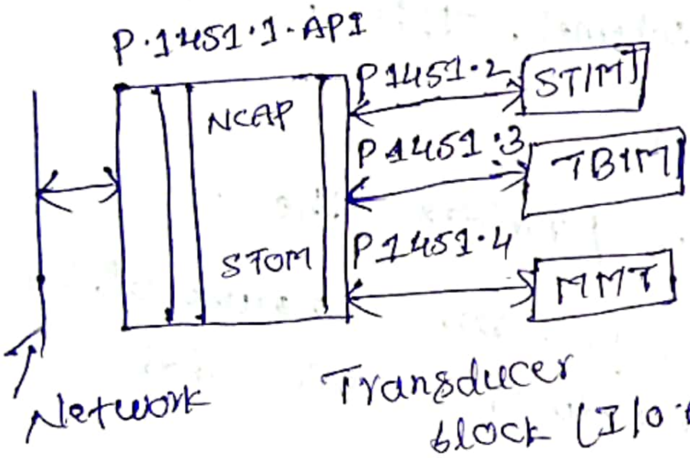


fig:- A communication scheme through IEEE 1451.

NCAP : Network capable Application processor

STOM : Smart Transducer object module

STIM : Smart Transducer Interface module.

TBIM : Transducer Bus Interface Module

MMT : Mixed mode Transducer.

The Automation :-

→ In modern control systems, Signal communication standards have been of tremendous significance.

→ The first signalling standard established was 4-20mA.

→ In 1981, work in international standards for PLC: in 1985, for field bus. and in 1987.

→ functional safety for programmable electric systems started but proprietory standards still continue to exist.

→ However, distributed control structure reduces the cost significantly by eliminating the need for long transmission lines between the controller and the sensors and actuators.

→ A typical scheme of such a structure is shown in figure.

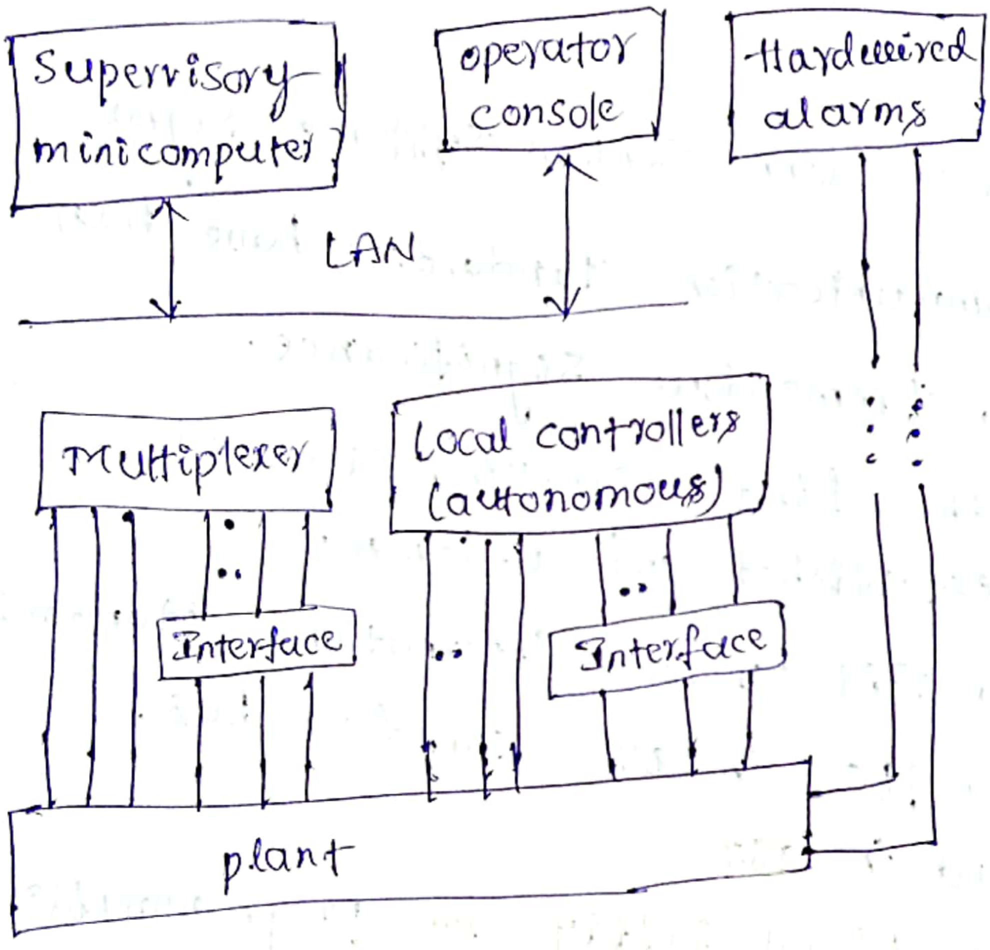


fig :- Distributed control structure.

Sensors Their Applications :-

Introduction :-

→ 'Sensors for miscellaneous applications'. Sensors elucidated here are only highlighted in terms of their applications.

→ This adaptation to specific applications has been given due consideration.

→ A little analysis of the sensor system has been made in some cases.

→ ~~obv~~. not all fronts of application can be covered in the present text though the ones presented offer a wider exposure.

ON-Board Automobile Sensors :-

Sensors for Automobiles, that is, automotive on-board sensors come with some special constraints. and features that include environment, reliability, cost, and resources and innovations.

→ Engine is the heart of the automobile which is exposed to vibration, dust, electrical, noise, extreme temperature variations,

→ one such sensor is the automobile has a temperature varying from -40 to 150°C and vibrational acceleration ranging from 3g - 30g.

→ Exposure to water, oil, ~~mud~~, electromagnetic interference, and the like are also to be taken into consideration for better performance.

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→ In present day mobile automobile systems, sensing is required to be done majorly for

(i) engine control
(ii) manouvering control
(iii) room and operational comfort control.
(iv) Safety and reliability. and
(v) fuel consumption control.

Flow-rate Sensors :-

→ For the conventional engines with carburettor,

→ such sensors are not necessary as the air-to-fuel ratio is self-adjustable here.

→ For the upcoming electronic fuel injection engines,

→ These sensors are made use of as the air volume input to the engine is estimated by flow-rate or pressure sensing.

→ ultrasonic flowmeters where the flow-rate is measured by measuring the difference between the speeds of sound both upstream and downstream.

→ Such sensors is yet limited because of large flow-rate changes and temperature variation.

→ Solid state sensors developed through semiconducting technology are used for sensing air and fuel flows.

→ The underlying principle is to use a heating element in the form of a transistor or a 'semiconductor' resistance bridge.

→ These can now be realized on silicon substrates.

→ Its schemes are shown in fig.

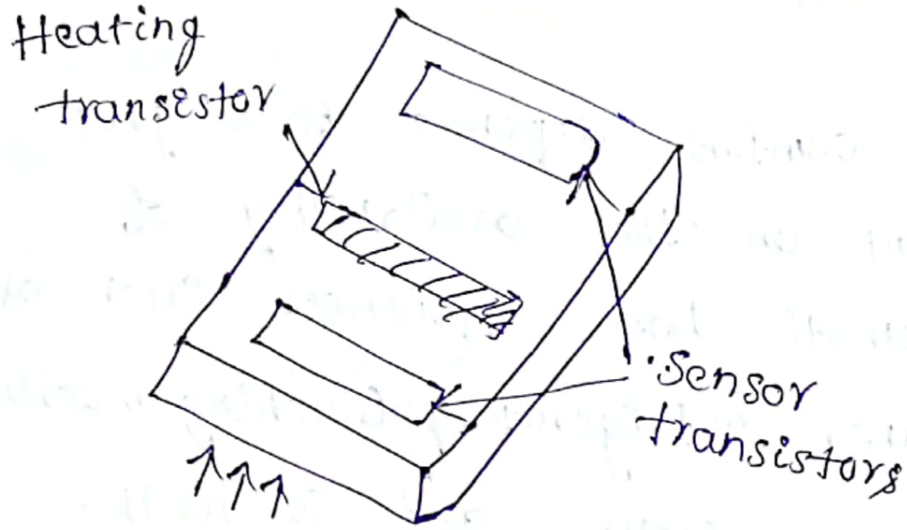

fig : (a)

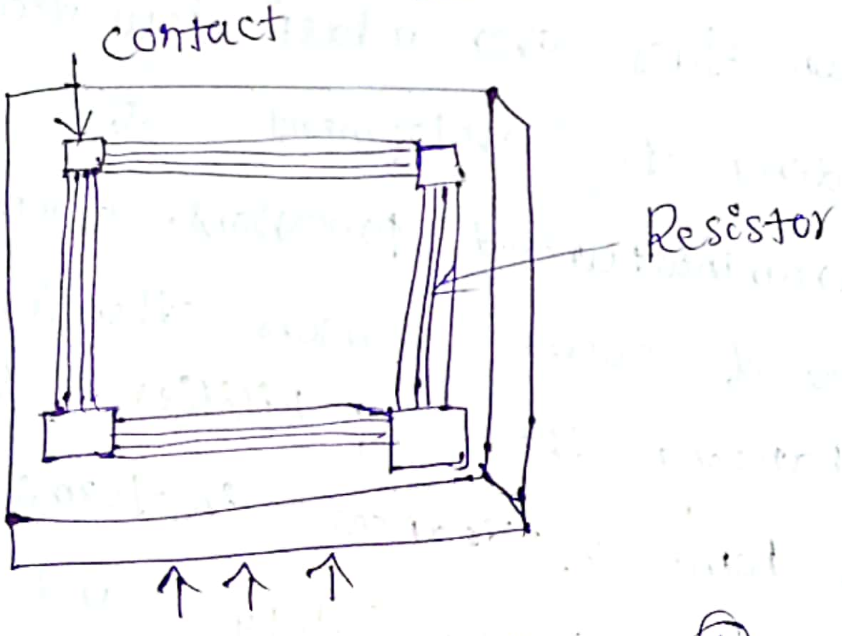

fig :- (b)

fig :- Examples of Semiconductor flow sensors.

Home Appliance Sensors :-

Home comfort depends to a great extent on the availability of automatic home appliances such as cleaner, refrigerator, washing machine, microwave ovens, and so forth.

→ semiconductor technology has grown fast over a last few decades leading to developments of microminiaturized processors. circuits, And of course sensors therefore enhancing the capabilities of the home applicances in terms of automation, safety, and efficiency.

→ Smart operation of the home appliances depends largely on appropriate sensors which have made the equipment more convenient, energy-economic, and safe.

→ Basically, the sensors are used in electronic control of the appliancy and when coupled with micro computers.

→ In the mechanical category, silicon pressure sensors, metal ~~diag~~ diaphragms, and potentiometers are used in carpet cleaners., while bellows element type are being used in refrigerators. potentiometers are also used in washing machines.

→ In the chemical type, humidity Sensors have considerable applications in microwave ovens, clothes dryers, air conditioners, and also in CVR camaras, while gas sensors are used in ovens, and exhaust fans.

→ Mangnetic sensors are widely used in electronic gadgets in entertainment there are Hall sensors in CVR camaras, Stereo sets and tape-recorders.

→ In the temperature sensing category, thermistors are extensively used in ovens, cooking ranges, refrigerators, dishwashers, dryers, air conditioners, exhaust fans, CD players, and stereoplayers.

→ Radiation sensors, that is photodiodes, and phototransistors are are used as the major elements in refregerators, washing machines, air conditioners, TV sets, CD players, and video disc players.

→ Photo diode LED assembly has also been used for frost detection in refrigerators. With frost, the light intensity received by the photo-detector is reduced as in the case of a rinsing system.

→ An alternative system for this use is piezocrystal oscillator and a PTC thermistor system.

→ Homes are moving towards being automated and for that along with the variety of sensors available, new sensors need be developed.

→ The development is already underway.

→ Three important categories in home automation are

(i) house control (ii) energy control/optimization, and

(iii) home security.

A block schematic of a home automation system with various sensors is shown in figure.

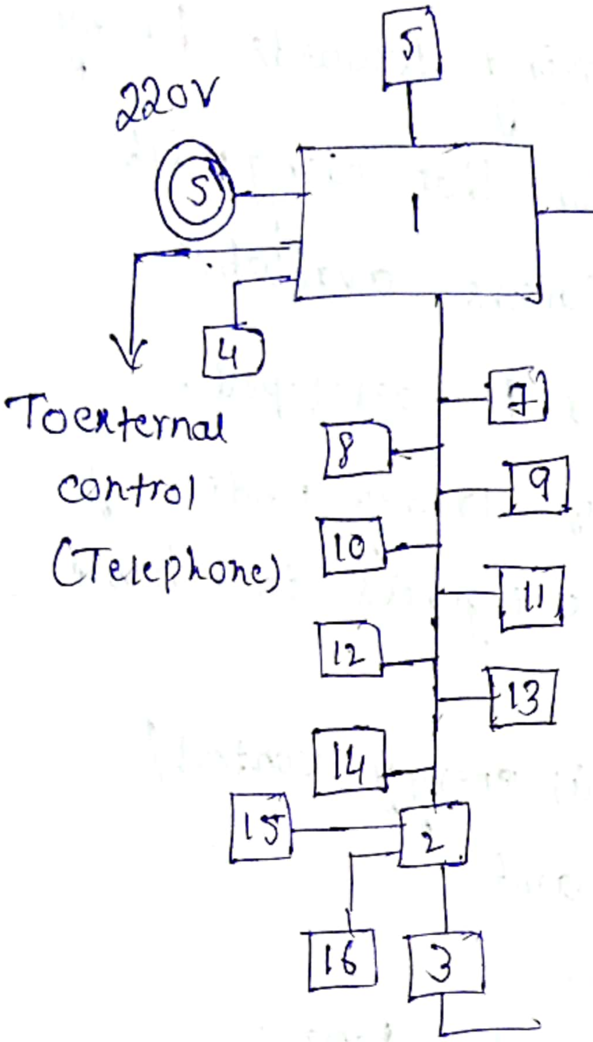

fig:- Block schematic of a house automation System.

(1) main control (2) and (3) secondary controllers (4) air conditioners (5) current sensors (6) light control (7) smoke control (8) ventilation, (9) security (10) gas (11) thermal/electrical keys (12) bath etc, (13) earthquake protection, (14) electrical keys (15) air adaptor (16) light (secondary).

Aerospace Sensors :-

sensors in aerospace applications have to ~~wis~~ withstand wide variation in physical conditions.

→ density of air changes from a free molecule to normal state, fluid flow temperatures vary from 20-350 K.

→ At supersonic speed, gases lose their near ideal behaviour.

→ In air, sensors are subjected to varying accelaration, rain, ice, and other environmental changes.

→ Parameters which are to be monitored for optimization are not new and include pressure, flow and flow direction, temperature, aircraft speed, fluid velocity, strain, thrust, force, accelaration, and so forth.

→ sensors that are used are not special though their installation, data acquisition, and processing are to be done.

Sensors for Manufacturing :-

- Manufacturing, basically is a controlled process or system - the key to the control being the sensors used in automated manufacturing.

→ Diagrammatic representation between sensors used in such manufacturing and various automation levels in a plant is shown in fig.

→ Increased Interconnection has been employed because of the invasion of the computer in manufacturing and special software based on process data available from signals delivered by the sensors at various stages and levels.

→ Quality Control is also an important area where sensorial assistance is now largely sought.

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→ Intelligent sensors are gradually becoming essential as they can interface with each other through organized software processing of electronic signals.

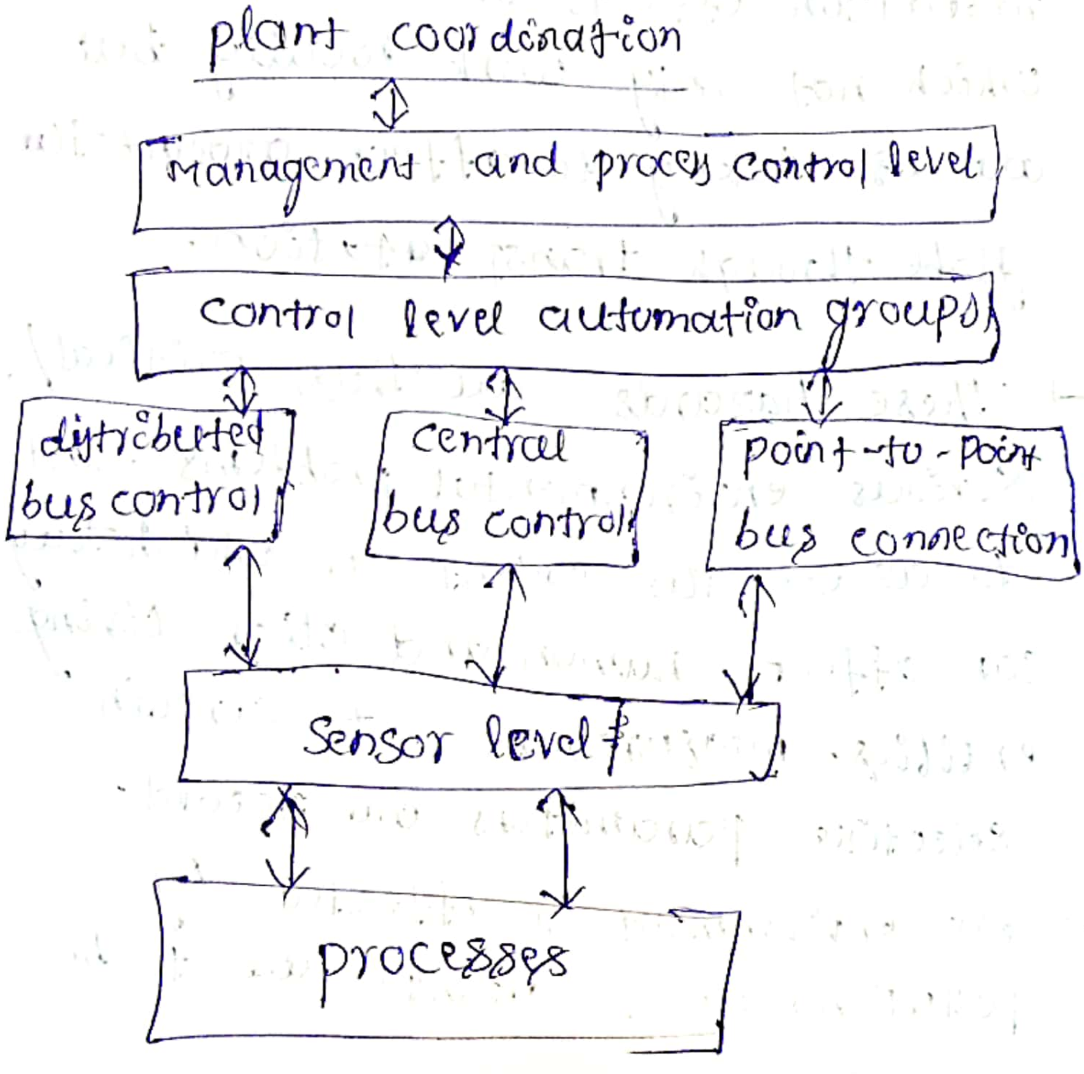

fig:- Interaction diagram between sensors and levels of operations.

Sensors for Environmental monitoring :-

Entire living world is now at risk. on counts of health and normal survivality due to hazards arising out of biological, chemical, and radiation effects on the environment which not only work locally but are also likely to affect around the globe through transporatation.

-) These hazards are thus, critical/. serious environmental problems and to assess the extent to which they can affect human and other living entities. measurement of certain selective parameters are needed.

-) As environment is affected by pollution, the pollutants are to be identified.

-) hazard occurring at a place is not endemic to that place alone and it is spread.

→ The three main ways that cause this spread are (i) atmosphere.
(ii) Surface water. and
(iii) ground water.
The manner in which these hazards affect human/living being can be given by simple chart as shown in fig.

→ ~~M~~ Monitoring the environment pollution again involves three steps, namely the
(i) collection of sample representative enough of the environmental pollution content.
(ii) pre-treatment of the sample using extraction, separation and so on. and
(iii) Analysis for identification and quantification of analytic pollutant in sample and expressing it in proper level of concentration.

→ similarly, analysis techniques differ depending on the type of sample.

→ The sensors / instrumentation in the analyzers are nothing new in general but their matching with pollutant and source characteristics are important.

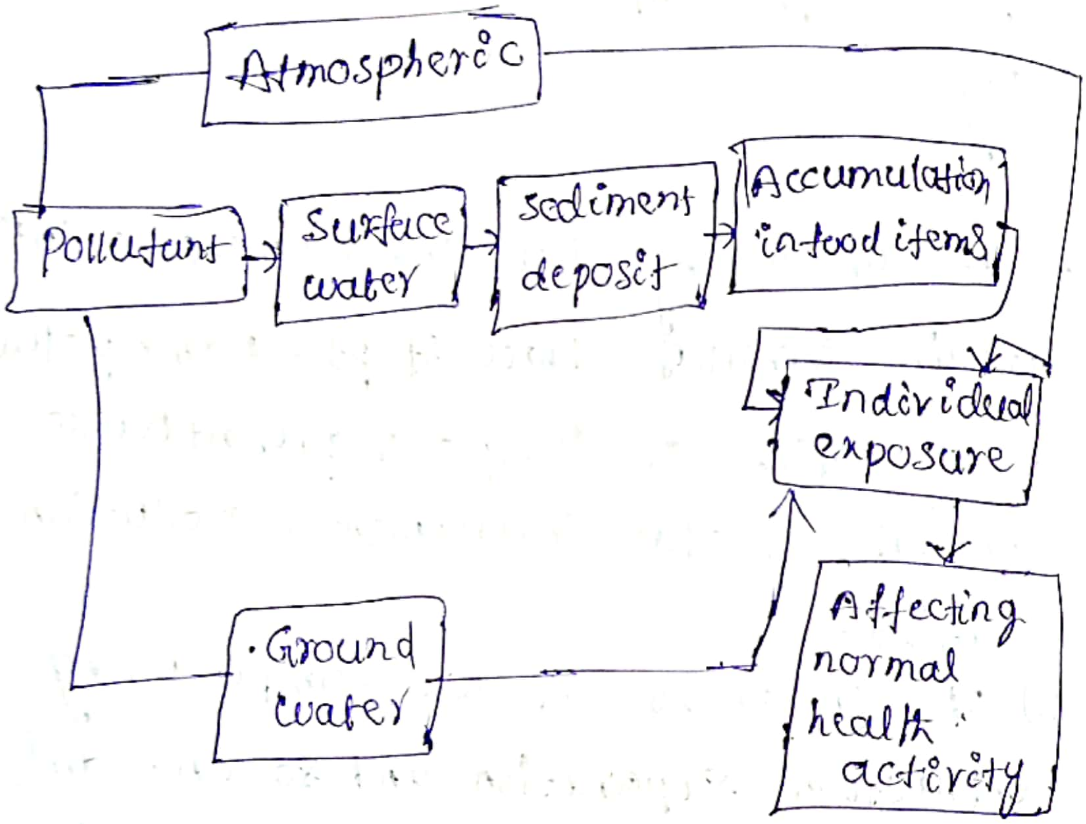

fig:- The eco-hazard.