Simple Application Programming

5.1 CMSIS Interrupt Control Functions

Table 15.2: CMSIS Interrupt Control Functions

Function	Descriptions
void NVIC_EnableIRQ (IRQn_Type IRQn);	Enable an interrupt. This function does not apply to system exceptions.
void NVIC_DisableIRQ (IRQn_Type IRQn);	Disable an interrupt. This function does not apply to system exceptions.
void NVIC_SetPendingIRQ (IRQn_Type IRQn);	Set the pending status of an interrupt. This function does not apply to system exceptions.
void NVIC_ClearPendingIRQ (IRQn_Type IRQn);	Clear the pending status of an interrupt. This function does not apply to system exceptions.
uint32_t NVIC_GetPendingIRQ (IRQn_Type IRQn);	Obtain the interrupt pending status of an interrupt. This function does not apply to system exceptions.
void NVIC_SetPriority (IRQn_Type IRQn, uint32_t priority);	Set up the priority level of an interrupt or system exception. The priority level value is automatically shifted to the implemented bits in the priority level register.
uint32_t NVIC_GetPriority (IRQn_Type IRQn);	Obtain the priority level of an interrupt or system exception. The priority level is automatically shifted to remove unimplemented bits in the priority level values.
void __enable_irq(void);	Clear PRIMASK. Enable interrupts and system exceptions.
void __disable_irq(void);	Set PRIMASK. Disable all interrupts including system exceptions (apart from hard fault and NMI).

5.2 Simple Interrupt Programming

General Overview of Interrupt Programming

Interrupts are essential for majority of embedded systems. For example, user inputs can be handled by an interrupt service routine so that the processor does not have to spend time checking the input interface status. In addition to handling user inputs, interrupts can also be used for other hardware interface blocks, peripherals, or by software.

In the Cortex-M0, the interrupt feature is very easy to use. In general, we can summarize the configuration of an interrupt service as follows:

• Set up the vector table (this is done by the startup code from a CMSIS-compliant device driver library).

• Set up the priority level of the interrupt. This step is optional; by default the priority levels of interrupts are set to level 0 (the highest programmable level).

• Define an interrupt service routine (ISR) in your application. This can be a C function.

• Enable the interrupt (e.g., using the NVIC_EnableIRQ() function).

By default the global interrupt mask PRIMASK is cleared after reset, so there is no need to enable interrupts globally.

The CMSIS has made these steps much easier, as the priority level and enabling of the interrupt can be carried out by functions provided in the CMSIS. The interrupt service routine is application dependent and will have to be created by a software developer. In most cases, you can find example code from the microcontroller vendors that will make software development easier. Depending on the peripheral design on the microcontroller, you might have to clear the interrupt requests inside the interrupt service routines. Please note that global variables used by the interrupt service routines need to be defined as volatile.

Dial Control Interface Example

In addition to switches, UARTs, and keypads, there are many other types of input devices. In recent years, dial controls have been used in many electronic gadgets. In this example we use a simple dial control to demonstrate simple interrupt programming in the Cortex-M0.

There are a number of ways to detect movement on a dial control interface. One simple implementation is to use two optical sensors with a rotary disc connected to a dial, as shown in Figure 15.7.

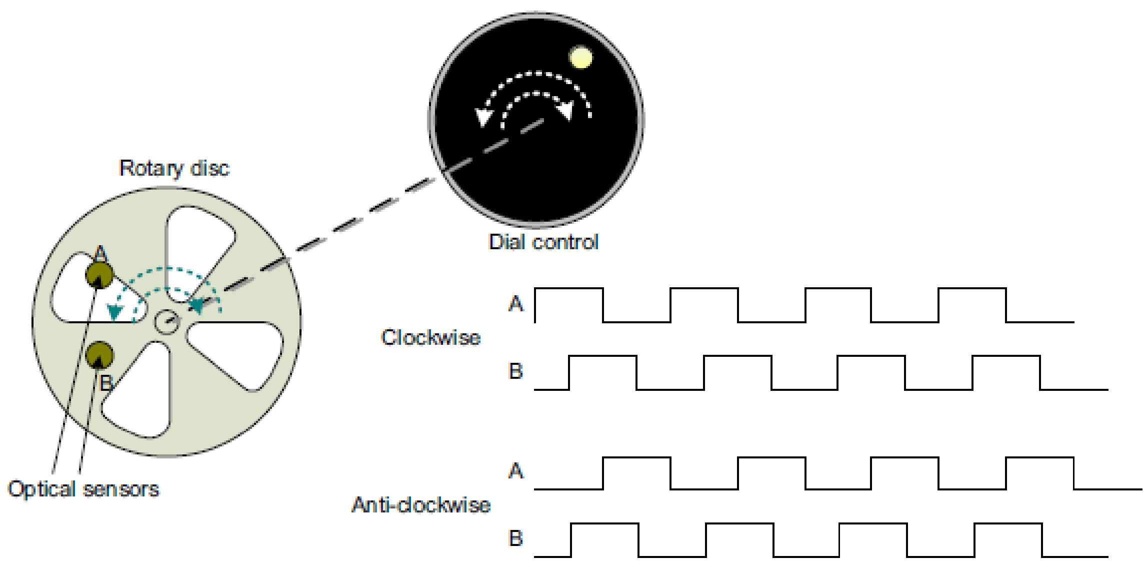


Figure 15.7:
Simple dial control implementation.

By detecting the edge transitioning of the two sensors, we can detect the rotation of the dial. This detection can be implemented on a Cortex-M0 microcontroller like the NXP LPC1114 quite easily. In this application example, we connect the two optical sensors to port 3 (P3_2 connected to sensor A, P3_3 connected to sensor B). We can then use the interrupt feature to detect when the dial is rotated. The NXP LPC1114 allows interrupt generation from port 3 on both rising and falling edges of signal transition. The interrupt handler needs to detect the direction of the dial movement from the previous state and the new state of the sensor's outputs, and then it will update software variables to inform the main application that the dial has been activated. The program flow for the dial control example is shown in the flowchart in Figure 15.8. In this example, we use the UART interface to output the position of the dial range from 0 to 255. In real applications, the position value of the dial control can be used in other ways and the UART setup code might not be required and could be removed if that is the case.

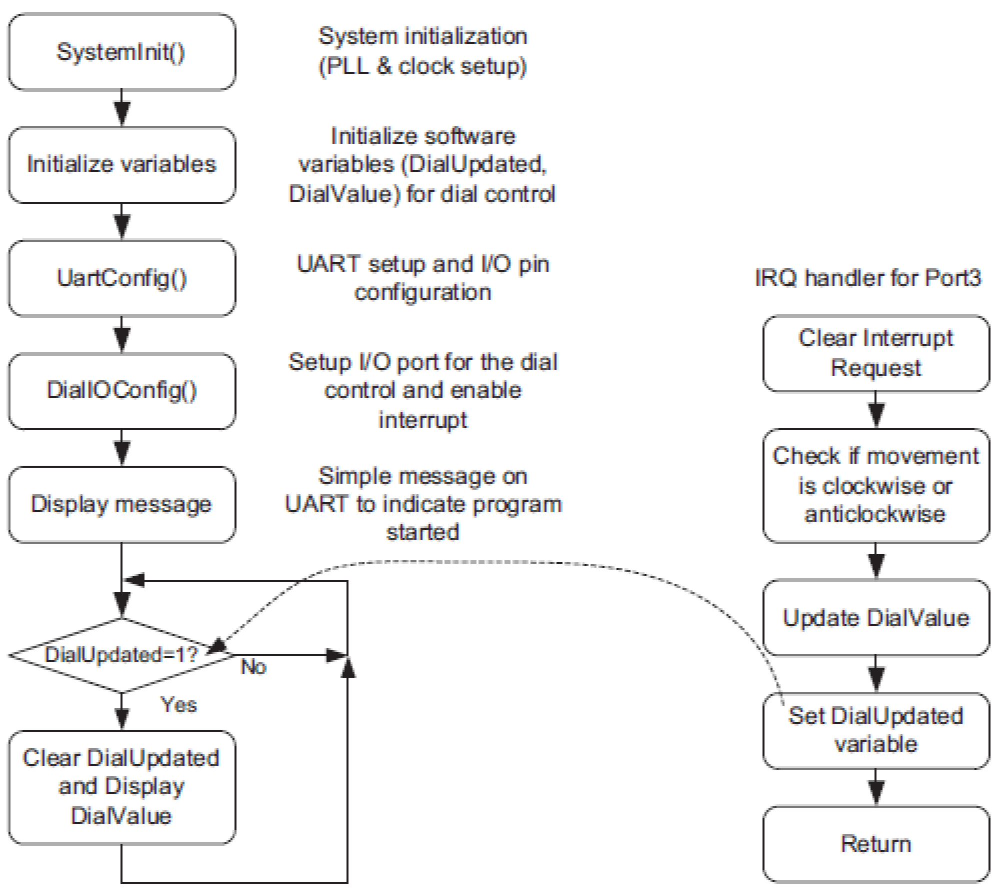


Figure 15.8:
Flowchart for simple dial control application.

The application contains the following files:

- startup_LPC11xx.s (the assembly startup code, as in previous example)
- system_LPC11xx.c (the system initialization function, as in previous examples)
- dial_ctrl.c (the dial control application)
- retarget.c (for text display functions, reuse the previous retarget example code)

Most of the files are identical to previous project examples. The only new file is the dial control code. To get the interrupt to work, the “DialIOCfg()” function uses a number of CMSIS functions. The rest of the code in “DialIOcfg” is used for configuring the pins for the input function and to generate interrupt on both rising and falling edges.

Unit-5

➢ Sensors:

A **sensor** is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena.

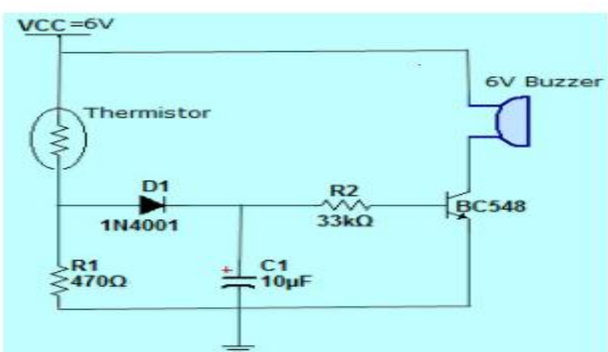
Example: Temperature Sensors-Thermistor, Thermocouple, Light Sensors- Light Dependent Resistor [LDR], light emitting Diodes [LED], Infrared LED, Proximity/Range Sensors, Humidity Sensors.

➢ Temperature Sensors:

Thermistor:

Thermistor is a type of resistor whose resistance changes rapidly with the small change in temperature. In other words, it is a type of resistor in which the flow of electric current changes rapidly with small change in temperature. The word **thermistor** is derived from the combination of words "thermal" and "resistor".

Working Principle of a Thermistor: This simple fire alarm circuit is based on thermistor and fire detection is possible through this circuit.



Simple Fire Alarm Circuit using Thermistor

- This circuit is very useful in home security systems.

- This circuit works based on the principle of switching property of the transistor
- The thermistor and resistor R1 forms potential divider n/w to drive the transistor
- The semiconductor materials used for thermistors are sensitive to temperature
- The transistor is switched ON by the voltage drop through the resistor R1.
- Consider the atmosphere's temperature is around 25°C, and then the resistance of the thermistor changes, then the voltage across the thermistor changes according to the principle of ohm's law V=IR.
- When the voltage across resistor R1 is low, then it is not sufficient to turn ON the transistor.
- When the temperature increases, the resistance of thermistor decreases, so that the drop across the resistor R1 increases which turns ON the transistor.
- When the transistor is turned ON, the current from Vcc starts to flow via 6V buzzer which generates a beep sound. The diode is used for enabling unidirectional conduction and the capacitor removes sudden transients from the thermistor.

Thermocouple:

A Thermocouple is a sensor used to measure temperature. Thermocouples consist of two wire legs made from different metals. The wires legs are welded together at one end, creating a junction. This junction is where the temperature is measured. When the junction experiences a change in temperature, a voltage is created. The voltage can then be interpreted using thermocouple reference tables to calculate the temperature.

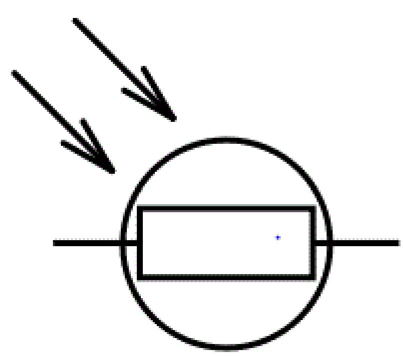
There are many types of thermocouples, each with its own unique characteristics in terms of temperature range, durability, vibration resistance, chemical resistance, and application compatibility. Type J, K, T, & E are "Base Metal" thermocouples, the most common types of thermocouples. Type R, S, and B thermocouples are "Noble Metal" thermocouples, which are used in high temperature applications.

- **Light Sensors:**

A **Light Sensor** is something that a robot can use to detect the current ambient **light** level - i.e. how bright/dark it is. There are a range of different types of **light sensors**, including 'Photoresistors', 'Photodiodes', and 'Phototransistors'.

Light Dependent Resistors: A **photoresistor** (or **light-dependent resistor**, **LDR**, or **photo-conductive cell**) is a light-controlled variable resistor. The resistance of a photoresistor decreases with increasing incident light intensity; in other words, it exhibits photoconductivity. A photoresistor can be applied in light-sensitive detector circuits, and light-activated and dark-activated switching circuits.

Working principle of LDR: A ***Light Dependent Resistor*** (LDR) or a photo resistor is a device whose resistivity is a function of the incident electromagnetic radiation. Hence, they are light sensitive devices. They are also called as photo conductors, photo conductive cells or simply photocells. They are made up of semiconductor materials having high resistance. There are many different symbols used to indicate a **LDR**, one of the most commonly used symbol is shown in the figure below. The arrow indicates light falling on it.

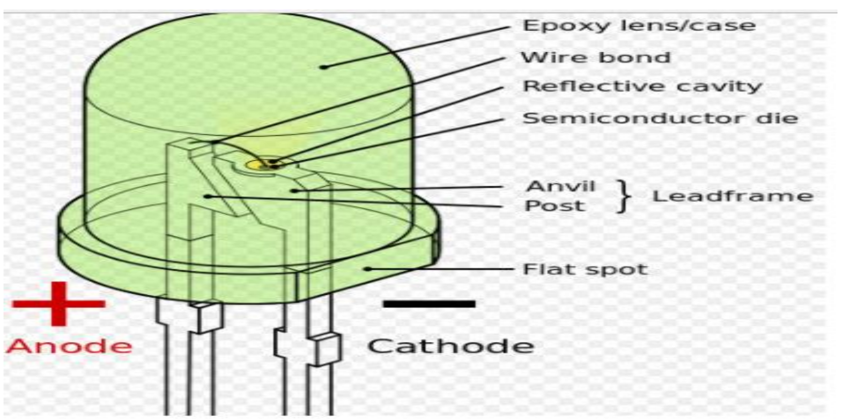


A **light dependent resistor** works on the principle of photo conductivity. Photo conductivity is an optical phenomenon in which the materials conductivity is increased when light is absorbed by the material. When light falls i.e. when the photons fall on the device, the electrons in the valence band of the semiconductor material are excited to the conduction band. These photons in the incident light should have energy greater than the band gap of the semiconductor material to make the electrons jump from the valence band to the conduction band. Hence when light having enough energy strikes on the device, more and more electrons are excited to the conduction band which results in large number of charge carriers. The result of this process is more and more current starts flowing throgh the device when the circuit is closed and hence it is said that the resistance of the device has been decreased. This is the most common **working principle of LDR**.

Light Emitting diodes:

A **light-emitting diode** (LED) is a semiconductor device that emits visible **light** when an electric current passes through it. The **light** is not particularly bright, but in most LEDs it is monochromatic, occurring at a single wavelength.

Working principle of LED: The lighting emitting diode is a p-n junction diode. It is a specially doped diode and made up of a special type of semiconductors. When the light emits in the forward biased, then it is called as a light emitting diode.



Light Emitting Diode

The light emitting diode simply, we know as a diode. When the diode is forward biased, then the electrons & holes are moving fast across the junction and they are combining constantly, removing one another out. Soon after the electrons are moving from the n-type to the p-type silicon, it combines with the holes, then it disappears. Hence it makes the complete atom & more stable and it gives the little burst of energy in the form of a tiny packet or photon of light.

Seven Segment LED:

A **seven-segment display** (**SSD**), or **seven-segment indicator**, is a form of electronic display device for displaying decimalnumerals that is an alternative to the more complex dot matrix displays.

Working Principle: LEDs are often grouped to form seven-segment display. The below Fig. shows the front of a seven segment display. It contains seven LEDs (A, B, C, D, E, F and G) shaped in a gure of 8. Each LED is called a segment. If a particular LED is forward biased, that LED or segment will light and produces a bar of light. By forward biasing various combinations of seven LEDs, it is possible to display any number from 0 to 9. For example, if LEDs A, B, C, D and G are lit (by forward biasing them), the display will show the number 3. Similarly, if LEDs C, D, E, F, A and G are lit, the display will show the number 6. To get the number 0, all segments except G are lit.

Organic LED:

OLED (Organic Light Emitting Diodes) is a flat light emitting technology, made by placing a series of organic thin films between two conductors. When electrical current is applied, a bright light is emitted. OLEDs are emissive display that do not require a backlight and so are thinner and more efficient than LCD displays (which do require a white backlight).

OLED displays are not just thin and efficient - they provide the best image quality ever and they can also be made transparent, flexible, foldable and even rollable and stretchable in the future. OLEDs represent the future of display technology!

An OLED display have the following advantages over an LCD display:

- Improved image quality - better contrast, higher brightness, fuller viewing angle, a wider color range and much faster refresh rates.
- Lower power consumption.
- Simpler design that enables ultra-thin, flexible, foldable and transparent displays
- Better durability - OLEDs are very durable and can operate in a broader temperature range

Infrared LED:

An Infrared light emitting diode (IR LED) is a special purpose LED emitting infrared rays ranging 700 nm to 1 mm wavelength. Different IR LEDs may produce infrared light of differing wavelengths, just like different LEDs produce light of different colors. IR LEDs are usually made of gallium arsenide or aluminum gallium arsenide. In complement with IR receivers, these are commonly used as sensors.

The appearance of IR LED is same as a common LED. Since the human eye cannot see the infrared radiations, it is not possible for a person to identify if an IR LED is working. A camera on a cell phone camera solves this problem. The IR rays from the IR LED in the circuit are shown in the camera.

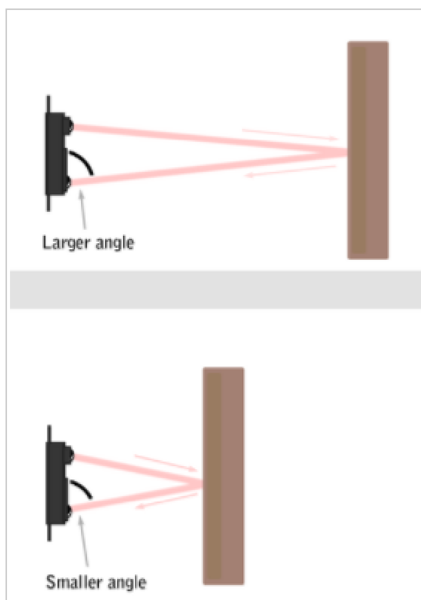
- **Proximity/Range Sensors:**

The Range Sensor combines an ultrasonic sensor to detect objects from approximately 5cm to 255 cm and an optical sensor to detect objects closer than 5cm. The Range Sensor combines ultrasonic and optical measuring elements to obtain a reading between 1cm and 255cm.

Sharp IR Sensor Technique:

A normal IR sensor can only tell if an object is bouncing back the IR light. There are times, however, when you also need to know how far away that object is. This is where the Sharp IR sensor comes into play. The Sharp sensor has a special detector that not only determines if there is light, but can also measure how far away an object is and return an analog value of the distance.

The detector in the Sharp IR sensor is similar to the imaging sensor found in digital cameras. Since the detector and the IR LED have a fixed distance and orientation relative to each other, the distance of an object will affect the angle at which the light from the IR LED hits the receiver. By looking at where the light hits the detector, it is possible to calculate the angle of the light and from that angle derive the distance to the object (all of which is done by the sensor itself).



➢ *The Sharp IR sensor can detect object distance*

- **Encoders:**

An **encoder** is a device, circuit, transducer, software program, algorithm or person that converts information from one format or code to another, for the purposes of standardization, speed or compression.

Optical Encoders:

Encoders employ various sensing techniques including the most common one: optical. In an optical encoder, a light source shines light on to or through a grated optical disk, so that the light beam passes through or is blocked.

The passage of light is sensed by an optical detector or read head, and a corresponding electrical signal is generated. Optical gratings, arranged as a series of markings, can be used to measure angle or motion. The scale of the markings is in the micron level, enabling precision measurement by the encoders.

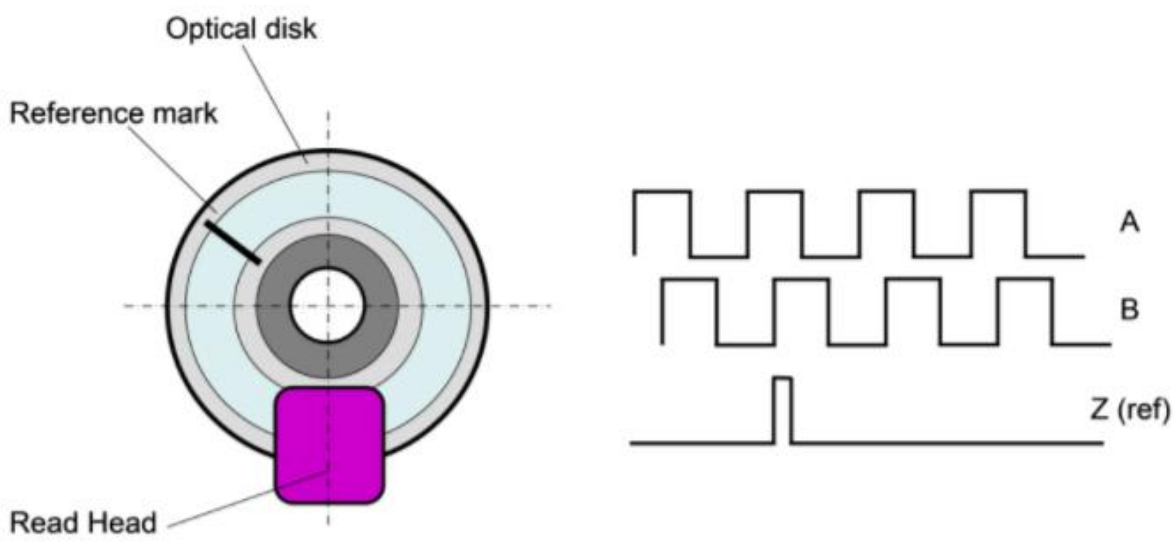


Figure 1. *Optical encoders use an optical sensor and an optical disk to measure angle.*

The packaged shaft encoder is a common format, where the encoder's shaft is mechanically connected with the host system. The encoder's shaft rotates in a bearing assembly and has an optical disk, which rotates relative to the optical detectors.

Electrically, the connection is often a multicore cable supplying DC power and carrying the encoder's position output data. The simple electrical interface is easy to specify and deploy, and is also widely available. However, the major drawback is that they cannot withstand harsh environments including shock, vibration, extreme temperatures, or foreign matter.

Little or no warning is provided for an imminent failure, which can result in an incorrect position data output, the worst case scenario, or an error message, the best case scenario.

Typically, the reporting of the incorrect position, not accompanied by an error message, is a more serious failure mode than having no reading at all, as it can lead to catastrophic results.

The datasheet usually specifies very tight tolerances for the position of the read head to the optical disk or grating, for larger diameter or ring encoders. This is done in order to achieve the stated measurement performance. Given the very small size of the optical features compared with the similarly-sized dust or dirt particles, such unpackaged ring encoders are especially susceptible to foreign matter.

As a consequence, optical encoders are typically not preferred for high reliability or safety-related applications.

Strengths: Widely available, high resolution, high accuracy possible

Weaknesses: Susceptible to foreign matter, catastrophic failure modes, delicate, limited temperature range (-20 to +70 °C)

- **Humidity Sensors:**

A humidity sensor (or hygrometer) senses, measures and reports both moisture and air temperature. The ratio of moisture in the air to the highest amount of moisture at a particular air temperature is called relative humidity. Relative humidity becomes an important factor, when looking for comfort.

Humidity sensors work by detecting changes that alter electrical currents or temperature in the air. There are three basic types of humidity sensors: capacitive, resistive and thermal. All three types of sensors monitor minute changes in the atmosphere in order to calculate the humidity in the air.

Capacitive: A capacitive humidity sensor measures relative humidity by placing a thin strip of metal oxide between two electrodes. The metal oxide's electrical capacity changes with the atmosphere's relative humidity. Weather, commercial and industries are the major application areas.

Resistive: Resistive humidity sensors utilize ions in salts to measure the electrical impedance of atoms. As humidity changes, so does the resistance of the electrodes on either side of the salt medium.

Thermal: Two thermal sensors conduct electricity based upon the humidity of the surrounding air. One sensor is encased in dry nitrogen while the other measures ambient air. The difference between the two measures the humidity.

- ## Actuators:

An **actuator** is a component of a machine that is responsible for moving and controlling a mechanism or system, for example by opening a valve. In simple terms, it is a "mover". An **actuator** requires a control signal and a source of energy.

Example: LED, Seven Segment LED, Static Seven Segment Display, OLED – Whhich are explained as above and also LCD which is explained below.

LCD:

A liquid crystal display or LCD draws its definition from its name itself. It is combination of two states of matter, the solid and the liquid. LCD uses a liquid crystal to produce a visible image. Liquid crystal displays are super-thin technology display screen that are generally used in laptop computer screen, TVs, cell phones and portable video games. LCD's technologies allow displays to be much thinner when compared to cathode ray tube (CRT) technology.

Liquid crystal display is composed of several layers which include two polarized panel filters and electrodes. LCD technology is used for displaying the image in notebook or some other electronic devices like mini computers. Light is projected from a lens on a layer of liquid crystal. This combination of colored light with the grayscale image of the crystal (formed as electric current flows through the crystal) forms the colored image. This image is then displayed on the screen.

Advantages of an LCD's:

- LCD’s consumes less amount of power compared to CRT and LED
- LCD’s are consist of some microwatts for display in comparison to some mill watts for LED’s
- LCDs are of low cost
- Provides excellent contrast
- LCD’s are thinner and lighter when compared to cathode ray tube and LED

Disadvantages of an LCD’s:

- Require additional light sources
- Range of temperature is limited for operation
- Low reliability
- Speed is very low
- LCD’s need an AC drive

- **Stepper Motors:**

A stepper motor is an electromechanical device it converts electrical power into mechanical power. Also it is a brushless, synchronous electric motor that can divide a full rotation into an expansive number of steps. The motor’s position can be controlled accurately without any feedback mechanism, as long as the motor is carefully sized to the application. Stepper motors are similar to switched reluctance motors.

The stepper motor uses the theory of operation for magnets to make the motor shaft turn a precise distance when a pulse of electricity is provided. The stator has eight poles, and the rotor has six poles. The rotor will require 24 pulses of electricity to move the 24 steps to make one complete revolution. Another way to say this is that the rotor will move precisely 15° for each pulse of electricity that the motor receives.

Driving Sequence of a Stepper Motor

Refer to page 120 and 121 in the textbook

- **Relays:**

The main operation of a relay comes in places where only a low-power signal can be used to control a circuit. It is also used in places where only one signal can be used to control a lot of circuits. The application of relays started during the invention of telephones. They played an important role in switching calls in telephone exchanges. They were also used in long distance telegraphy. They were used to switch the signal coming from one source to another destination. After the invention of computers they were also used to perform Boolean and other logical operations. The high end applications of relays require high power to be driven by electric motors and so on. Such relays are called contactors.

Types of Relays: Refer to textbook Page number: 128 and 129.

- **ADC:**

In electronics, an **analog-to-digital converter** (**ADC**, **A/D**, or **A-to-D**) is a system that converts an analog signal, such as a sound picked up by a microphone or light entering a digital camera, into a digital signal. An ADC may also provide an isolated measurement such as an electronic device that converts an input analog voltage or current to a digital number representing the magnitude of the voltage or current.

ADC interfacing: Control Interface, Data interface

Read from page No. 97- 99

- **Buses:**

Processor-Memory Buses: A memory bus is made up of two parts: the data bus and the address bus. The data bus is responsible for the transfer of information between the memory and the chipset. The wider a data bus is, the higher its performance since it can allow more data to pass through in the same amount of time; this is called data bandwidth. The address bus communicates with the system on where specific information can be located or stored when data either enters or leaves the memory. The speed and delays of an action made in a computer system depends greatly on the address bus since it is the entity locating the information. Its width depicts the amount of system memory a processor can read or write into.

Peripheral buses: A peripheral bus is a computer bus designed to support computer peripherals like printers and hard drives. The term is generally used to refer to systems that offer support for a wide variety of devices, like Universal Serial Bus, as opposed to those that are dedicated to specific types of hardware, like SATA. This usage is not universal, some definitions include any bus system that is not a system bus, including examples like PCI.[1] Others treat PCI and similar systems as a third category, the expansion bus.

Parallel vs Serial Buses: serial communication is the process of sending data one bit at a time, sequentially, over a communication channel or computer bus. This is in contrast to parallel communication, where several bits are sent as a whole, on a link with several parallel channels. Serial communication is used for all long-haul communication and most computer networks, where the cost of cable and synchronization difficulties make parallel communication impractical. Serial computer buses are becoming more common even at shorter distances, as improved signal integrity and transmission speeds in newer serial technologies have begun to outweigh the parallel bus's advantage of simplicity and to outstrip its disadvantages.

Half duplex Connection: Communication or transmission in which only one party at a time can send or receive voice signals or data, and the other party has to wait for its turn. Citizen band (walkie talkie) radios are **half-duplex** devices, but a telephone is a full-**duplex**device.

Full duplex Connection: Simultaneous two-way data or voice transmission. A telephone conversation is **full-duplex** (both parties, if they so wish, may talk at the same time and be heard), but a walkie talkie conversation is **half-duplex** (one talks, the other listens).

Synchronous bus:

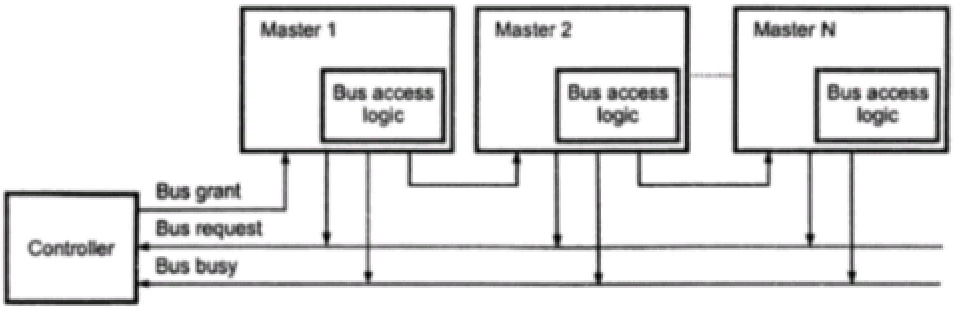
- Transmitter and receivers are synchronized of clock.
- Data bits are transmitted with synchronization of clock.
- Character is received at constant Rate.
- Data transfer takes place in block.
- Start and stop bit are required to establish communication of each character.
- Used in high – speed transmission.

Asynchronous bus:

- Transmitters and receivers are not synchronized by clock.
- Bit’s of data are transmitted at constant rate.
- Character may arrive at any rate at receiver.
- Data transfer is character oriented.
- Start and stop bits are required to establish communication of each character.
- Used in low – speed transmission.

Daisy chaining scheme for bus arbitration:

- The system connections for Daisy chaining method are shown in fig below.



- It is simple and cheaper method. All masters make use of the same line for bus request.
- In response to the bus request the controller sends a bus grant if the bus is free.
- The bus grant signal serially propagates through each master until it encounters the first one that is requesting access to the bus. This master blocks the propagation of the bus grant signal, activities the busy line and gains control of the bus.
- Therefore any other requesting module will not receive the grant signal and hence cannot get the bus access.

Talk Session between Master and Its Slaves of an I2C device:

Now let's have a look at the talk session between a master and its slaves. Refer to Figure 5.9.

i) First, the master issues a START signal. This signal causes all the slaves to come to attention and listen. The start condition corresponds to the action of the master pulling the SDA line low, when the clock (SCL) is high.

ii) The first byte sent by the master is the address. This address (7-bit) is sent serially on the SDA line (MSB first). Note that the bits on the SDA line are synchronized by the clock signal on the SCL line which means that the data on the SDA line is read during the time that the clock on the SCL line is high (data is valid at the L to H transition of the clock).

iii) Just after this, the master also sends the R/W signal indicating the direction of data transfer (see Figure 5.9 a). Note that all activities are synchronized by the clock.

iv) Only one of the slaves will have the broadcasted address, and on realizing that its address matches with this address, the particular slave responds by sending an 'acknowledge' signal back to the master.

v) Now a byte can be received from the slave if the R/W bit is set to READ, or be written to the slave, if otherwise (see Figure 5.9b).

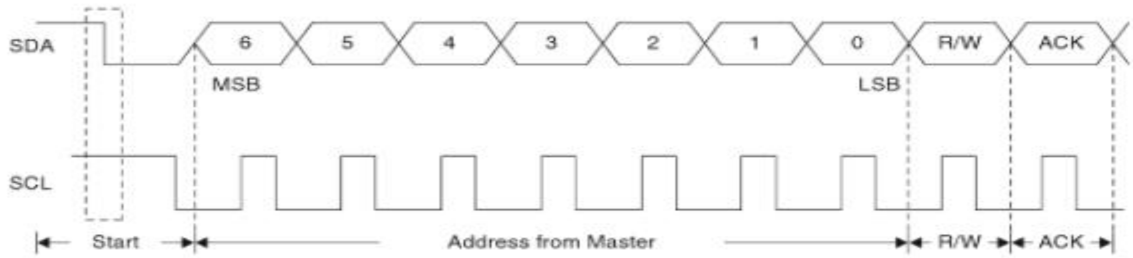


Figure 5 9a | The START condition and broadcast of the address by the master

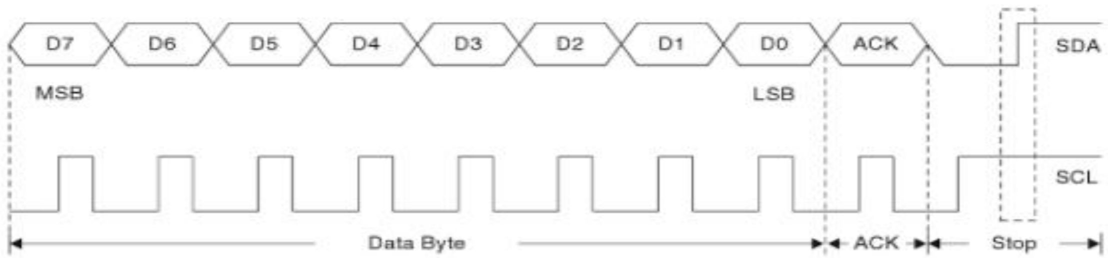


Figure 5.9b | Data transfer between the master and slave

vi) Once this data transfer is over, the device (master or slave) that has received the byte sends an acknowledge signal. Acknowledgement is when the receiver drives SDA low.

vii) If more bytes are to be transferred, steps v and vi are repeated.

viii) After this, the master pulls the SCL high, and then the SDA line also. This amounts to a STOP condition when the bus is idle, also indicating that it is available for use by other slaves.

The I2C bus was originally developed as a multi-master bus. This means that more than one device initiating transfers can be active in the system. In such a case, each master will have to arbitrate for the bus. I2C controllers have the additional hardware and protocol for this.

There are three standards for I2C bus and have the following three speeds:

i) Slow (under 100 Kbps)
ii) Fast (400 Kbps)
iii) High-speed (3.4 Mbps)