University of Dhaka
Department of Computer Science and Engineering
CSE-2205: Introduction to Mechatronics

Lec-7: Light Sensors + Motion Sensors

Mechatronics: Electronic Control Systems in Mechanical Engineering by W. Bolton

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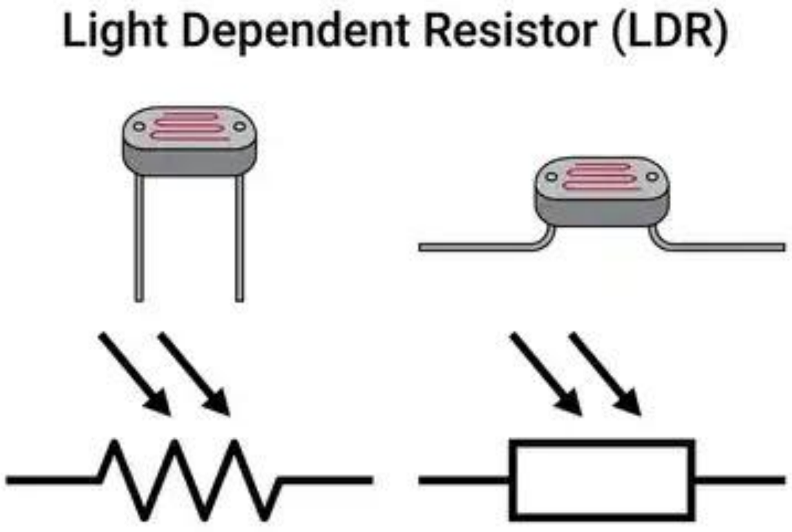
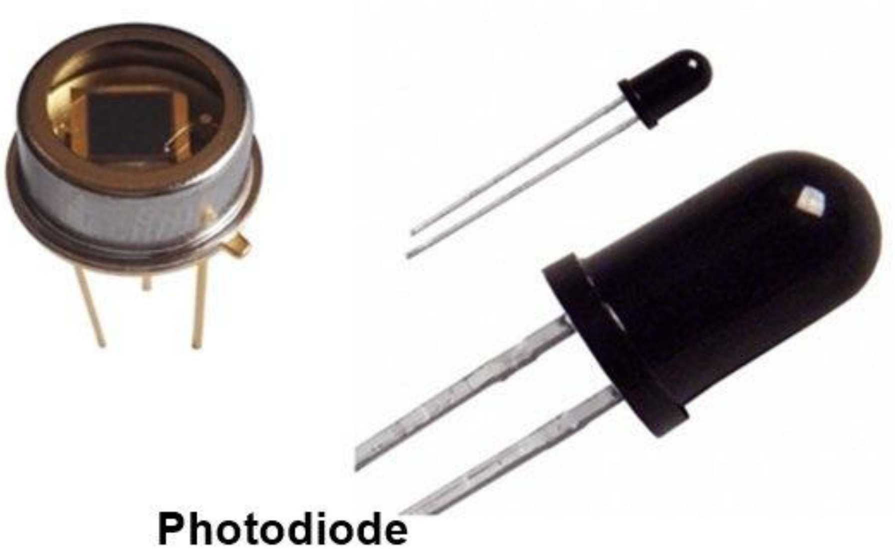
Light sensors are devices that detect and measure light intensity, converting it into an electrical signal for further processing.

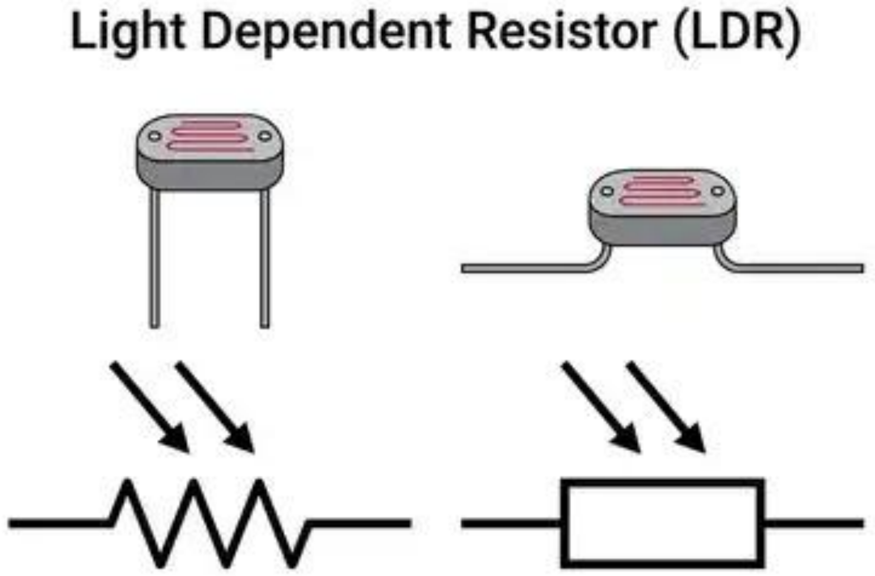




1.2 Light Dependent Resistor (LDR)

A Light Dependent Resistor (LDR), or photoresistor, is a light sensor that *changes its resistance based on the amount of light it receives*.

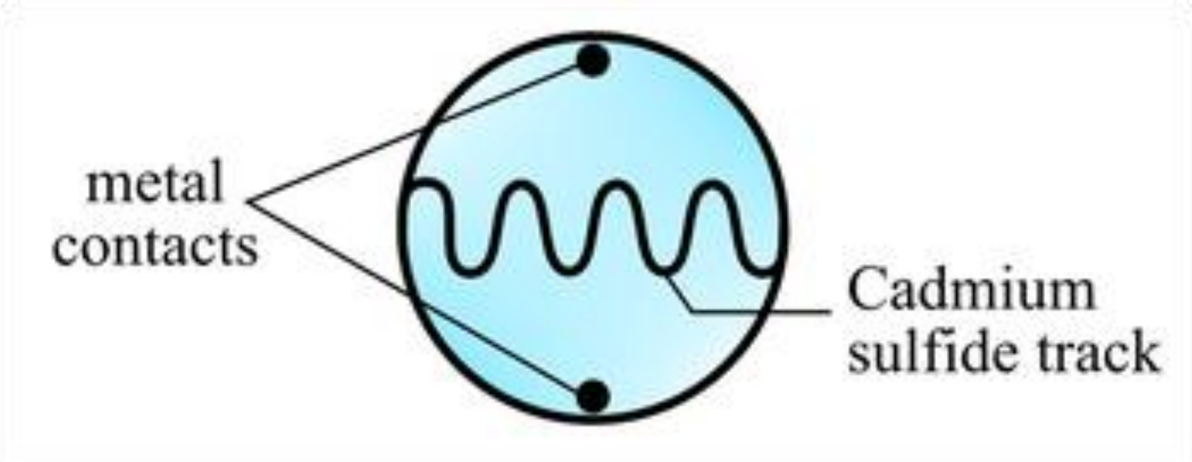
When *exposed to light, its resistance decreases*, allowing more current to pass through; when in *darkness, its resistance increases*, reducing current flow.



Construction

Material: LDRs are *made from semiconductive materials*, typically cadmium sulfide (CdS) or cadmium selenide, which respond to photons in visible light.

Structure: They have a *zigzagged or spiral pattern of material* on a ceramic base to *increase the surface area exposed to light*.

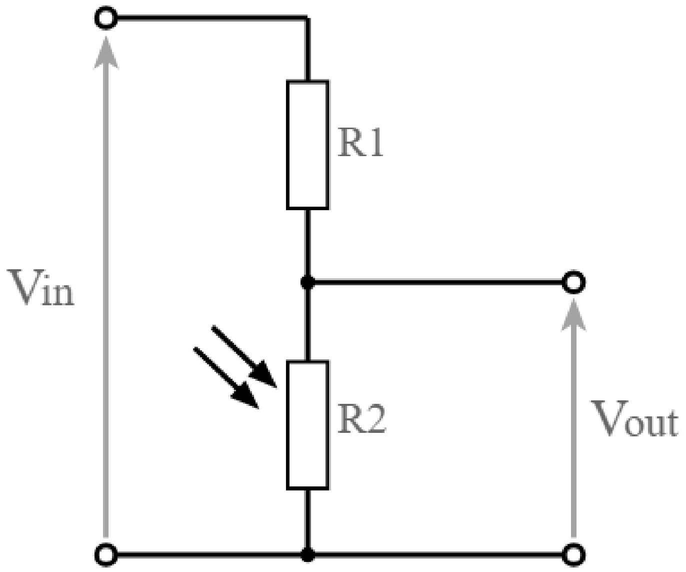


Working Principle:

The LDR operates on the principle of photoconductivity. *When photons hit the sensor, they excite electrons* in the semiconductive material, decreasing its resistance and increasing conductivity.

High Light Intensity: The *resistance of the LDR decreases as more photons excite* the electrons, creating a large current flow.

Low Light Intensity: The *resistance of the LDR increases when fewer photons are available* to excite the electrons, resulting in less current.



$$V_{out} = V_{in} \times \frac{R_{LDR}}{R_{LDR} + R_{fixed}}$$

Suppose an LDR is placed in a circuit with a 10V supply voltage and a fixed 1kΩ resistor in series. The LDR's resistance R_{LDR} at a specific light level is measured to be 2kΩ.

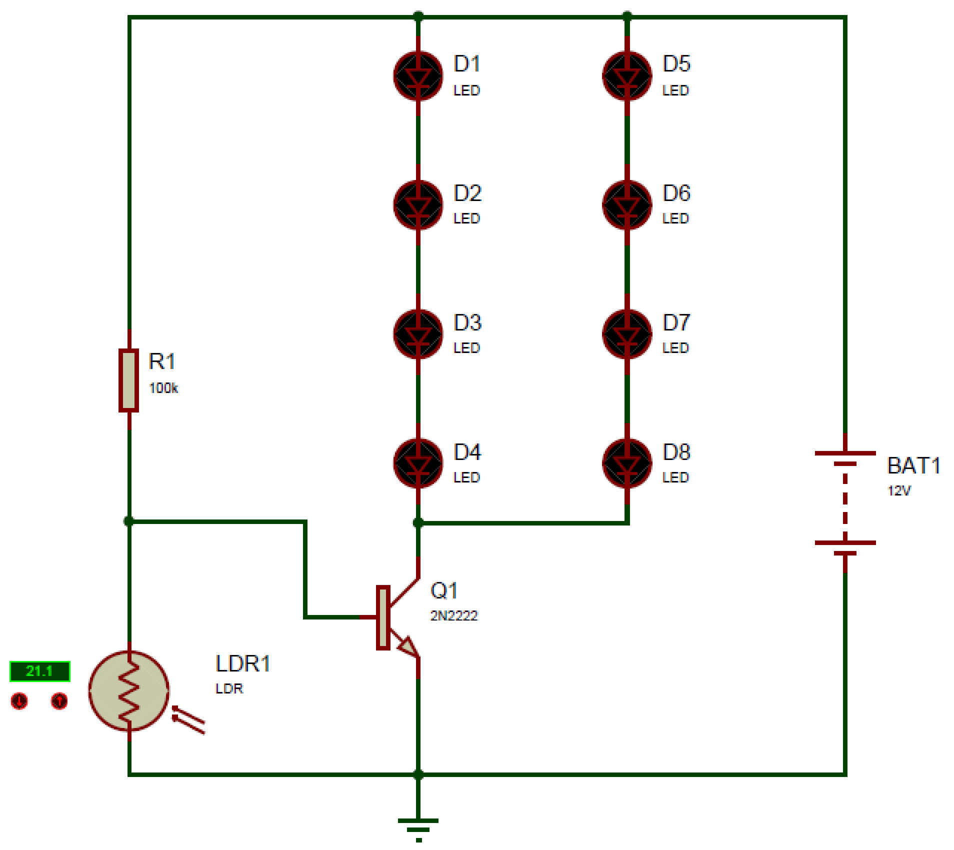
$$V_{out} = 10V \times \frac{2000\,\Omega}{1000\,\Omega + 2000\,\Omega}$$

$$V_{out} = 10V \times \frac{2000}{3000} = 10V \times 0.666 = 6.66V$$

Applications

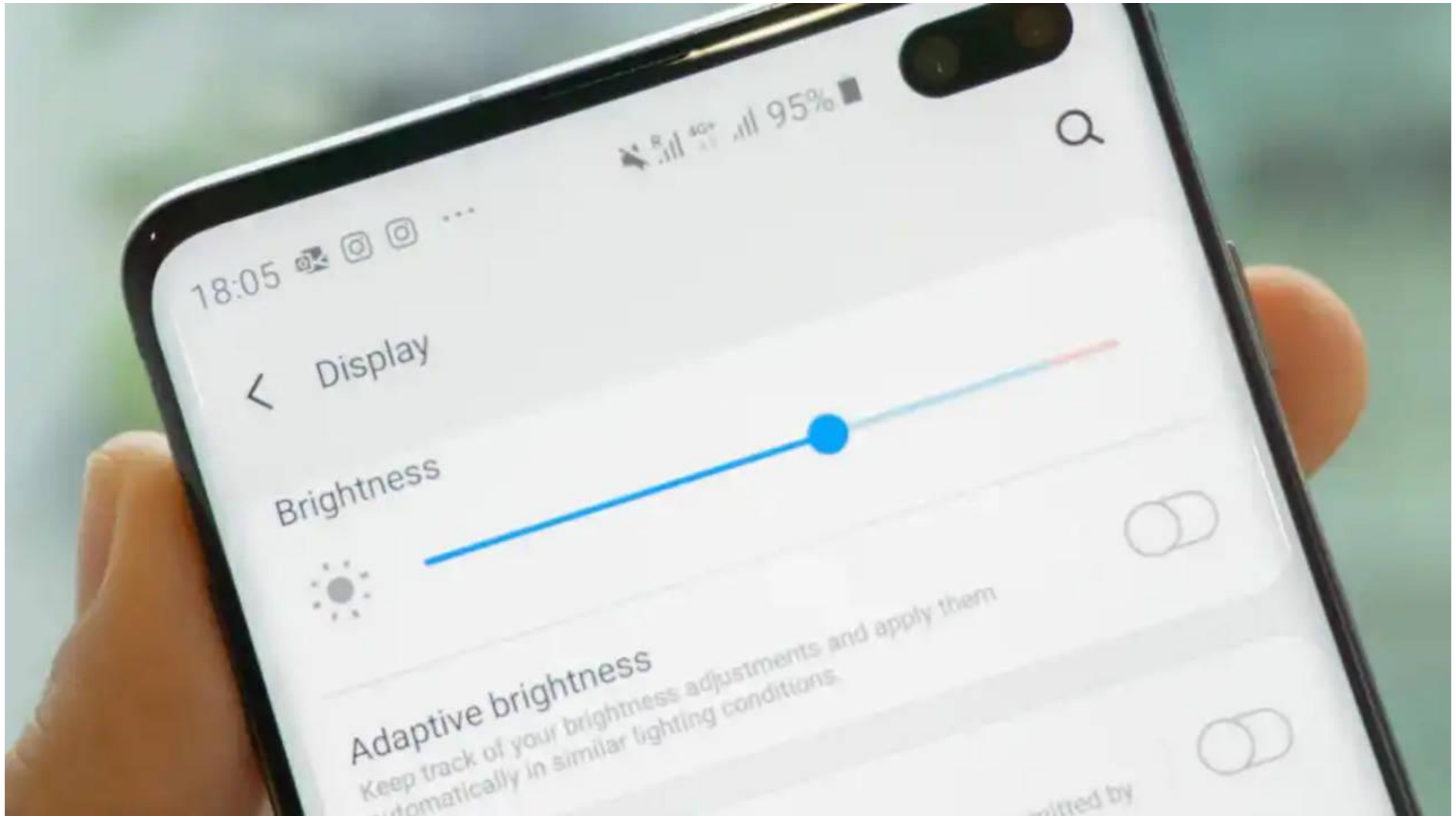
Automatic Street Lighting:

LDRs control street lights by *<u>switching them on at dusk and off at dawn</u>*.



Brightness Adjustment in Displays:

Used in smartphones and monitors to *<u>adjust screen brightness based on ambient light</u>*.



Photographic Equipment:

LDRs help in *adjusting camera exposure settings* by detecting light levels.

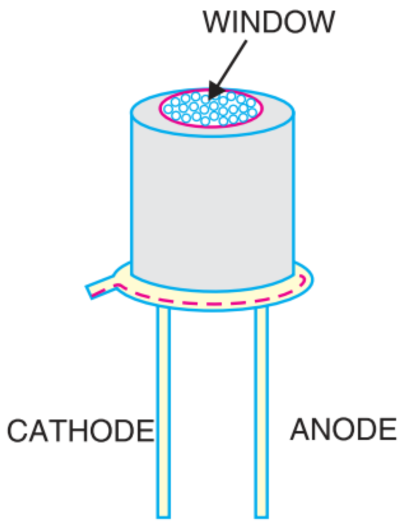
Security Systems:

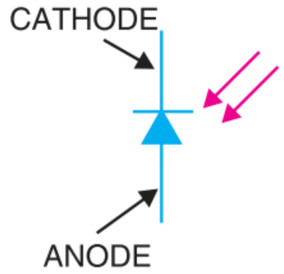
Can trigger alarms or lights *when light levels change unexpectedly*, indicating *movement or intrusion*.

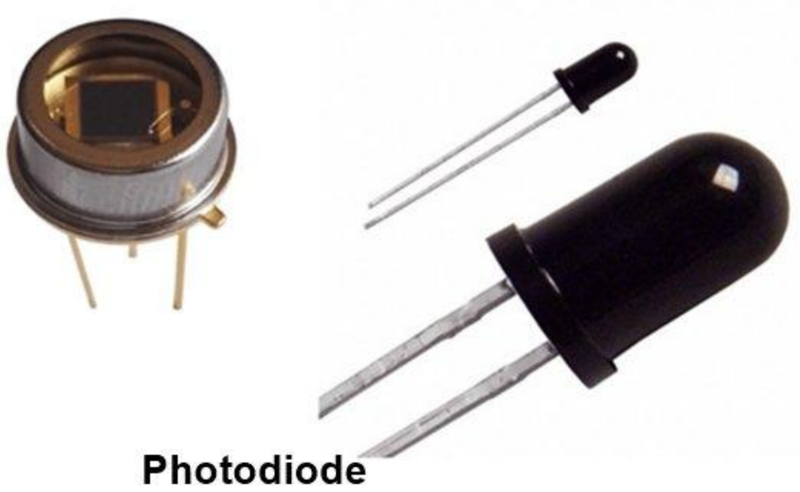
1.3 Photodiode

A photodiode is a *semiconductor device* that *converts light into an electrical current*.

It operates based on the principle of the *photoelectric effect*, where photons of light energy excite electrons within the semiconductor material, creating an *electron-hole pair that generates a current*.



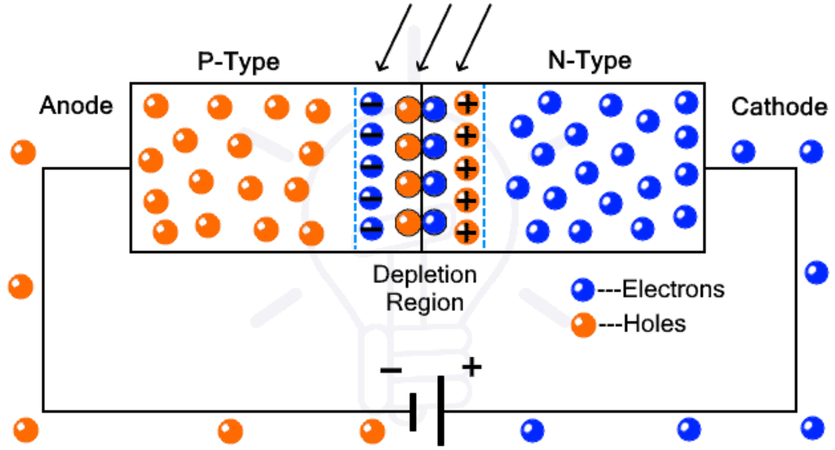




Construction

Material: Photodiodes are typically *made from semiconductor materials like silicon or germanium*.

Structure: They have a p-n junction, similar to diodes, with the *junction exposed to light*. Photons *striking the junction generate electron-hole pairs*, resulting in a current proportional to the light intensity.



Photodiode Working

Working Principle

Photodiodes are usually operated in **reverse bias** mode, where the n-side is connected to the positive terminal and the p-side to the negative terminal. This setup *widens the depletion region*, enhancing the device's sensitivity to light.

1. **No Light (Dark Mode)**: In the absence of light, a *minimal "dark current" flows due to thermal activity* within the diode.

2. **Light Exposure**: *When light (photons) strikes the depletion region*, it *excites electrons, creating electron-hole pairs*. The *electric field at the p-n junction separates these charges*, generating a photocurrent. The *current is proportional to the intensity of the light*.

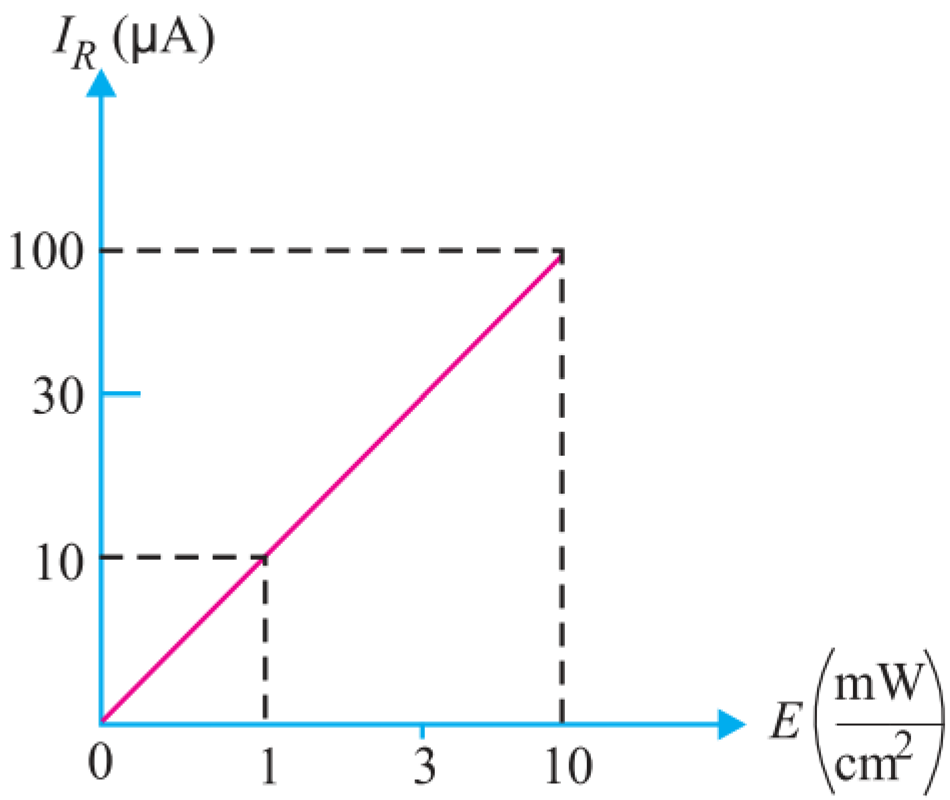
A photo-diode differs from a rectifier diode in that when its pn junction is exposed to light, the reverse current increases with the increase in light intensity and vice-versa.

- When *no light is incident on the pn junction* of photo-diode, the *reverse current I_r is extremely small*. This is called *dark current*. The resistance of photo-diode with no incident light is called *dark resistance*.

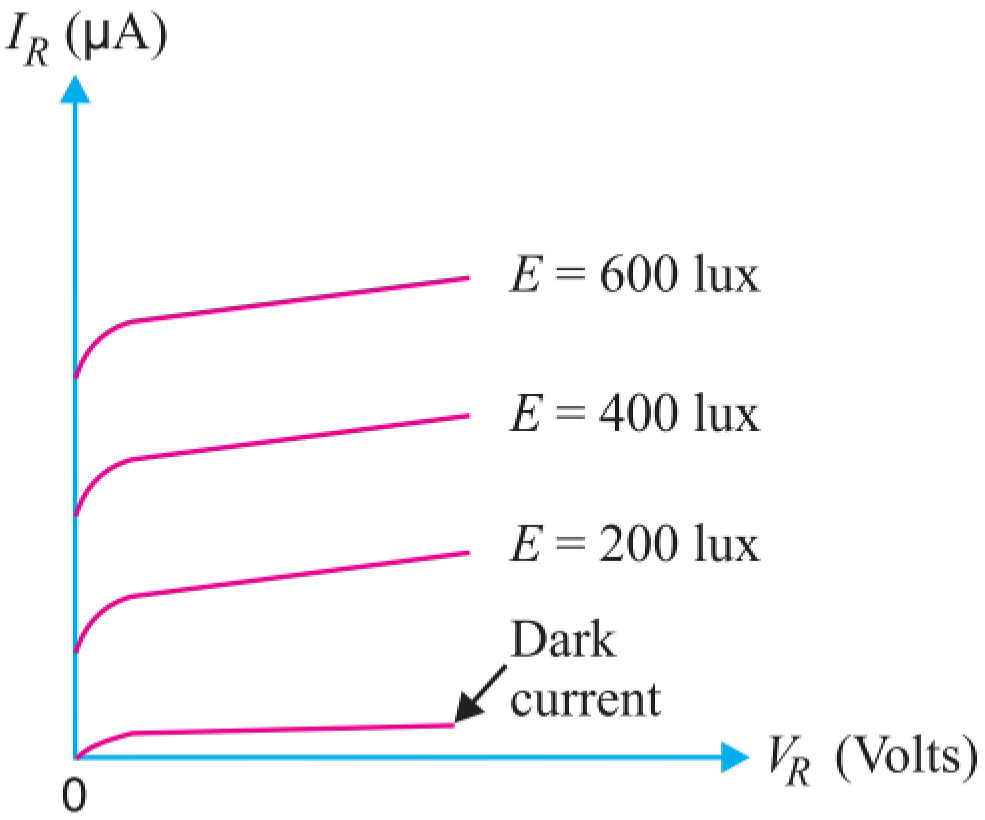
$$\text{Dark resistance of photo-diode, } R_R = \frac{V_R}{\text{Dark current}}$$

- As the *intensity of light* incident on the pn junction *increases*, the *reverse current also increases*.

In other words, as the incident light intensity increases, the *resistance of the device (photo-diode) decreases*.



Reverse current-Illumination curve



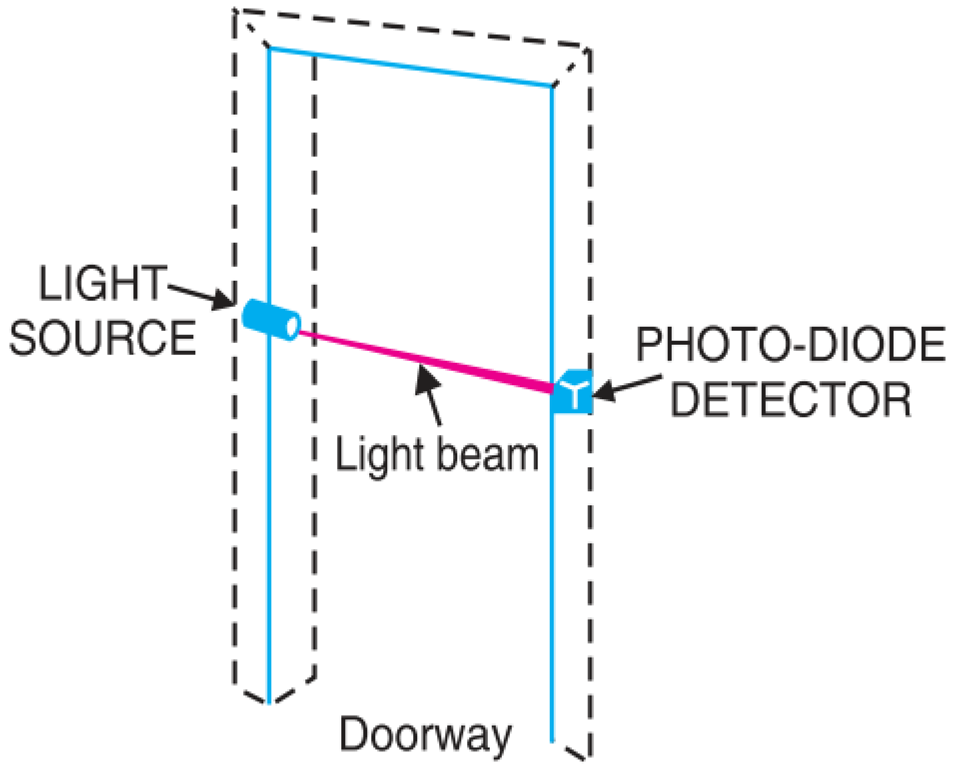
Reverse voltage-Reverse current curve

Applications of Photo-diodes

Alarm circuit using photo-diode:

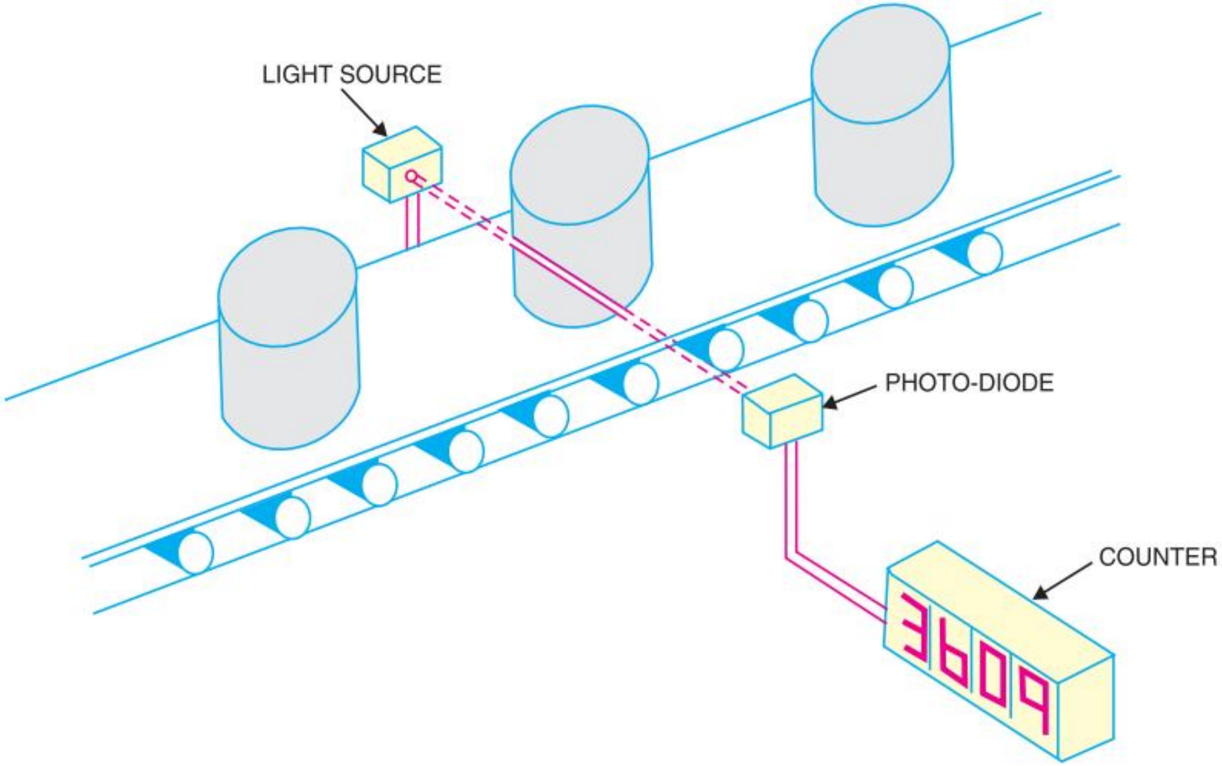
Light from a light source is allowed to fall on a photo-diode fitted in the doorway. The *reverse current I_R will continue to flow* so long as the *light beam is not broken*.

If a person passes through the door, light *beam is broken and the reverse current drops to the dark current level*. As a result, *an alarm is sounded*.



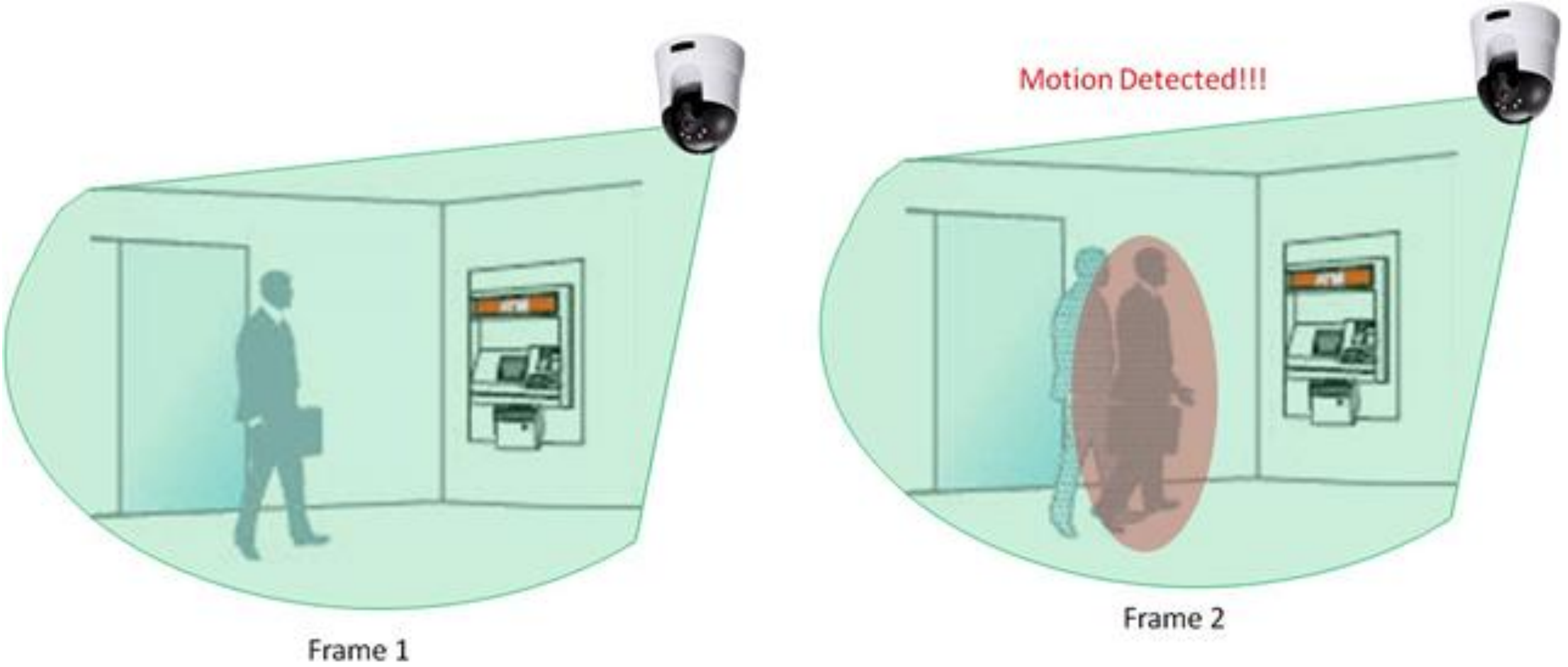
Counter circuit using photo-diode

A photodiode may be used to *count items on a conveyor belt*. In this circuit, a source of light sends a concentrated beam of light across a conveyor to a photo-diode. *As the object passes*, the *light beam is broken*, I_R drops to the dark current level and the *count is increased by one*.



2. Motion Sensors

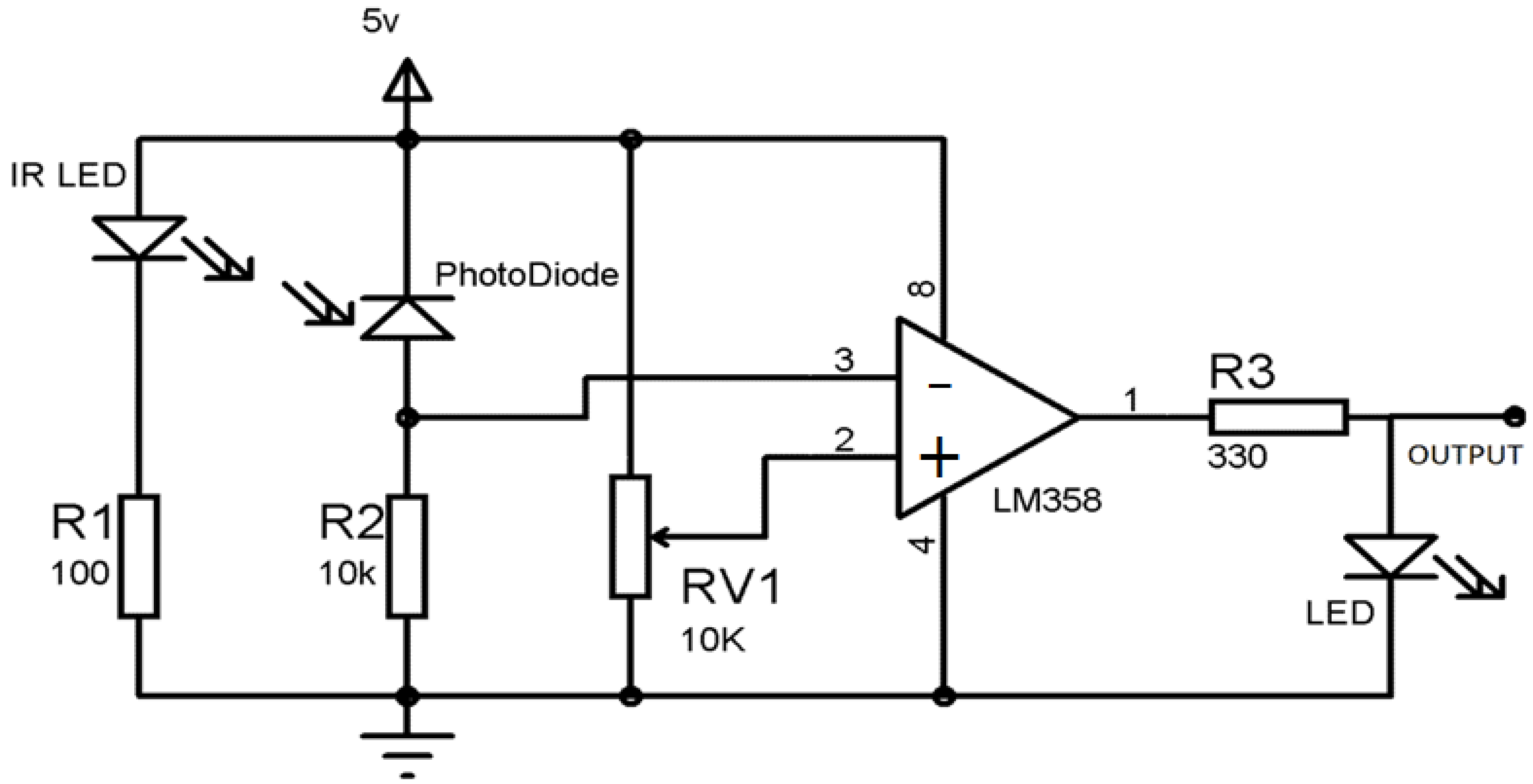
Motion sensors are devices that *detect movement* or *changes in their immediate environment* and *trigger a response* based on this detection.



2.1 IR Sensor

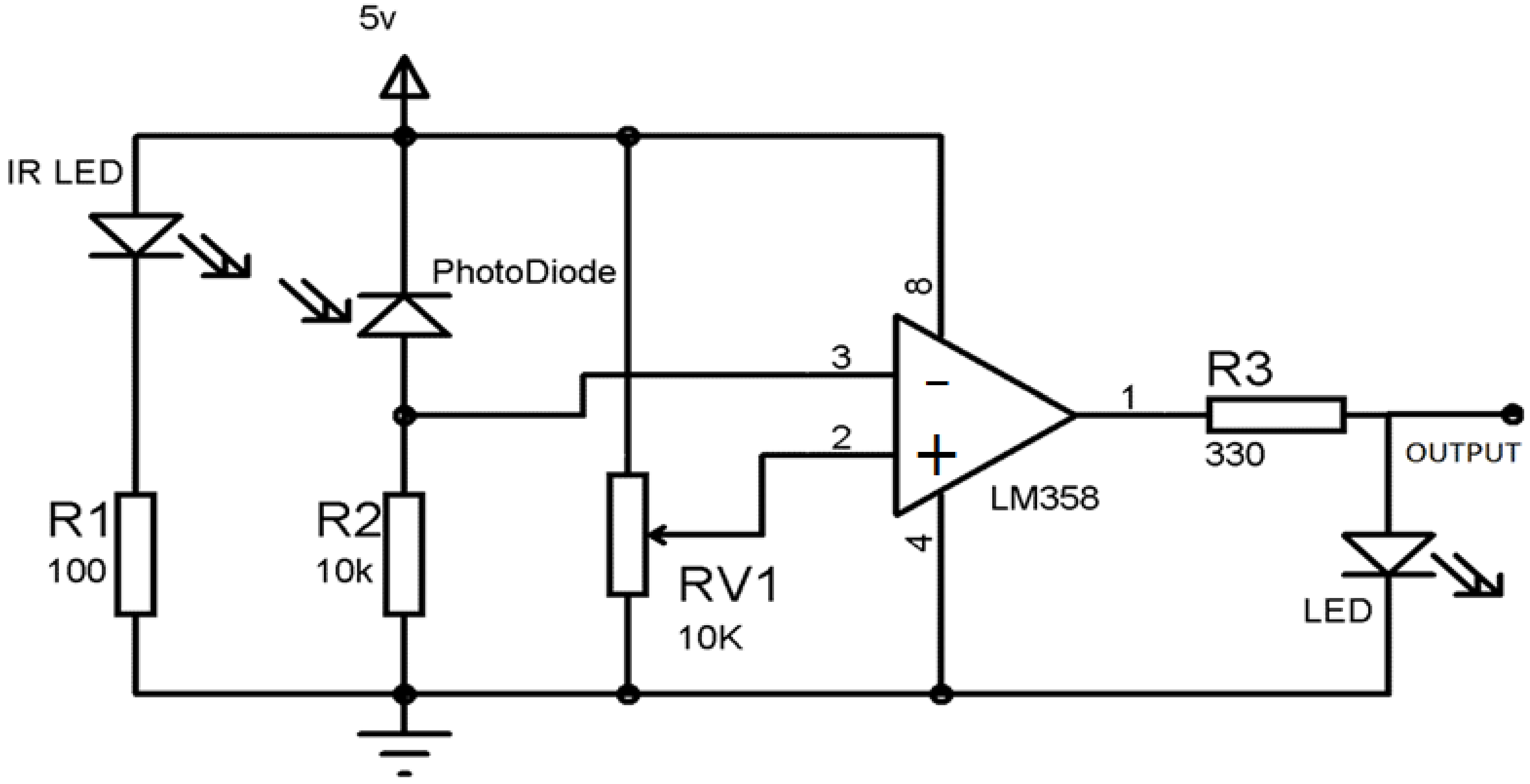
2.1.1 Passive IR sensor

detect changes in infrared radiation emitted by objects in their field of view.



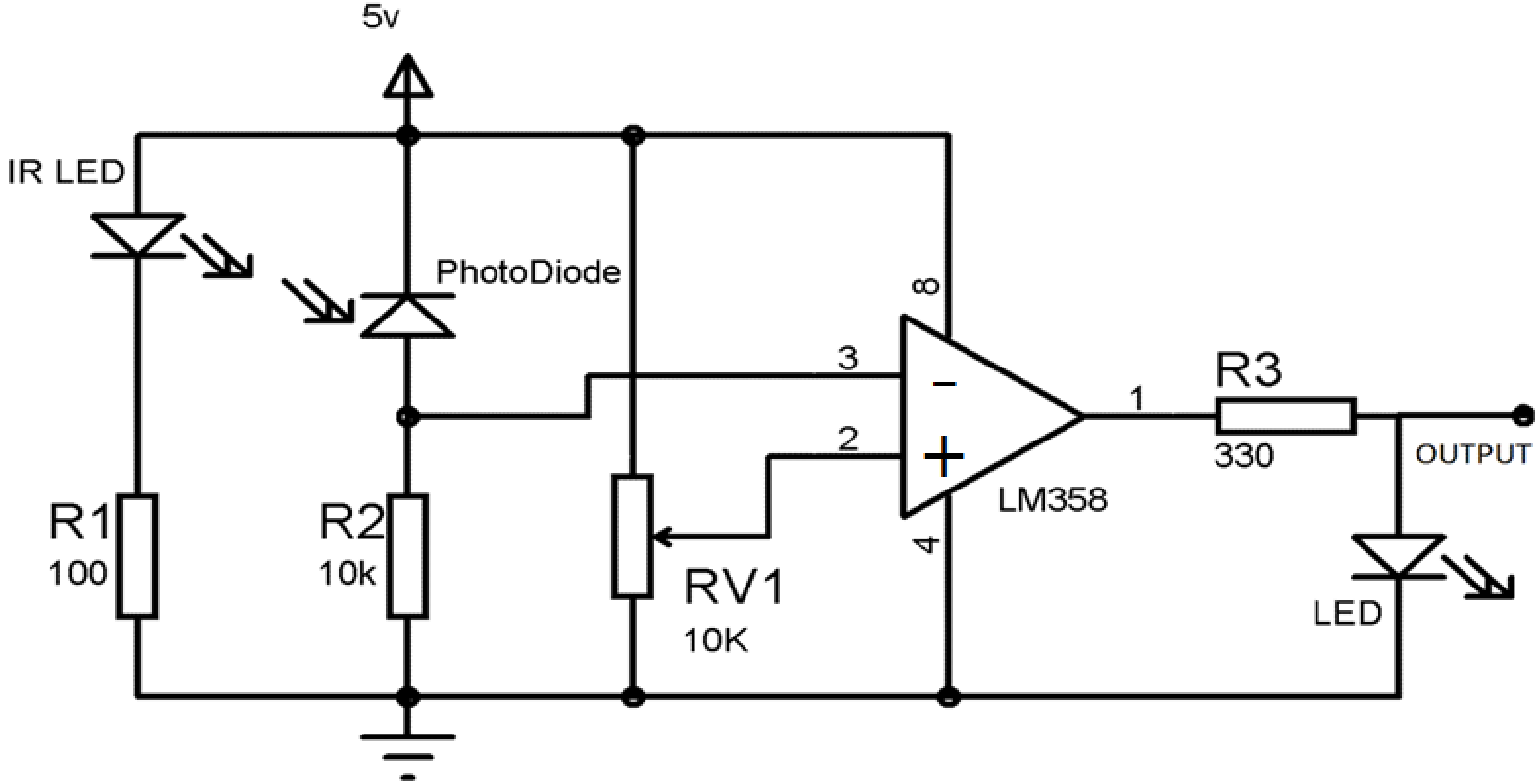
Stable State (No Motion):

When there's *no motion*, the amount of *infrared radiation hitting the sensor remains constant*, resulting in a *stable output voltage*.



Motion Detection:

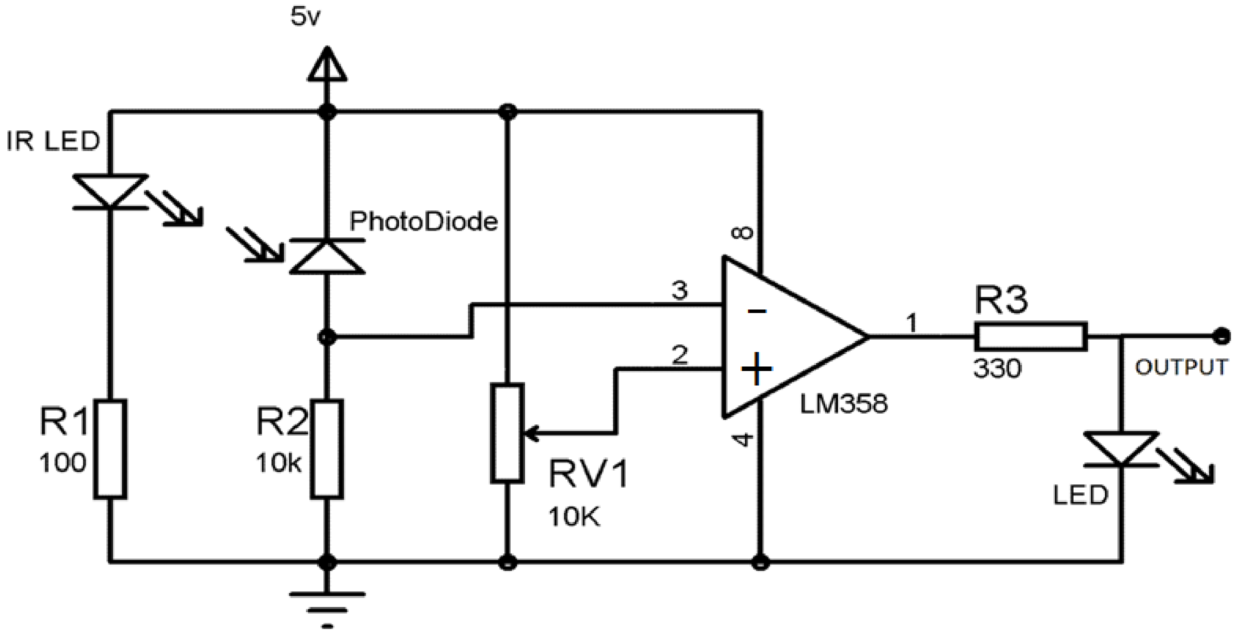
When an object (like a person or animal) moves across the sensor’s field of view, *it causes a rapid change in infrared radiation levels*. This *change alters the sensor’s output voltage*.



Signal Output:

The PIR sensor has internal circuitry, often with an operational amplifier, that detects this change in voltage. When motion is detected:

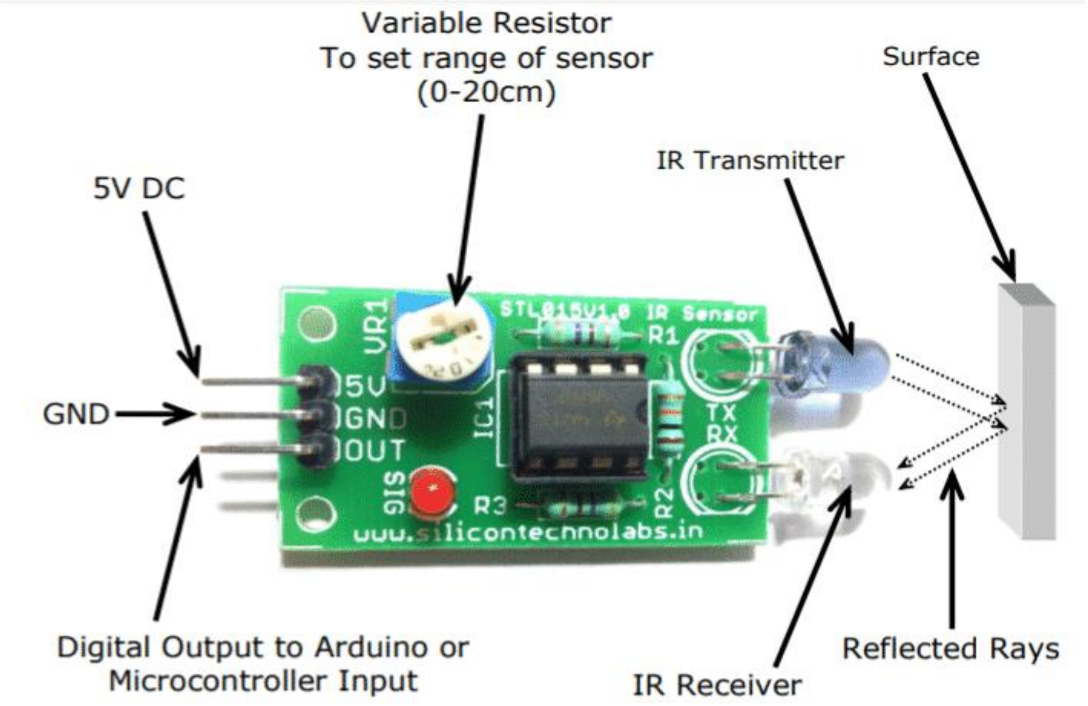
- The *output signal goes high (logical 1), indicating motion*.
- When *no motion is detected, the output returns to low* (logical 0).



2.1.2 Active IR Sensors

An *IR emitter shoots out a beam of light*, facing an in-line receiver. If *nothing is in the way*, the *receiver sees a signal*.

If the *receiver fails to see an IR beam*, it *detects that an object is between the emitter and the receiver*, and therefore *present in the monitored area*.



2.1.3 Applications of IR sensor

PIR Sensor based Automatic Door Opening System

The main aim of this project is to opening and closing of doors, in places wherein a person’s presence is mandatory – for instance, hotels, shopping malls, theaters, etc.

This project consists of a PIR sensor that senses the presence of the human body and sends pulses to the 8051 microcontroller.

This microcontroller controls the motor driver by sending suitable pulses to its input and enable pins.

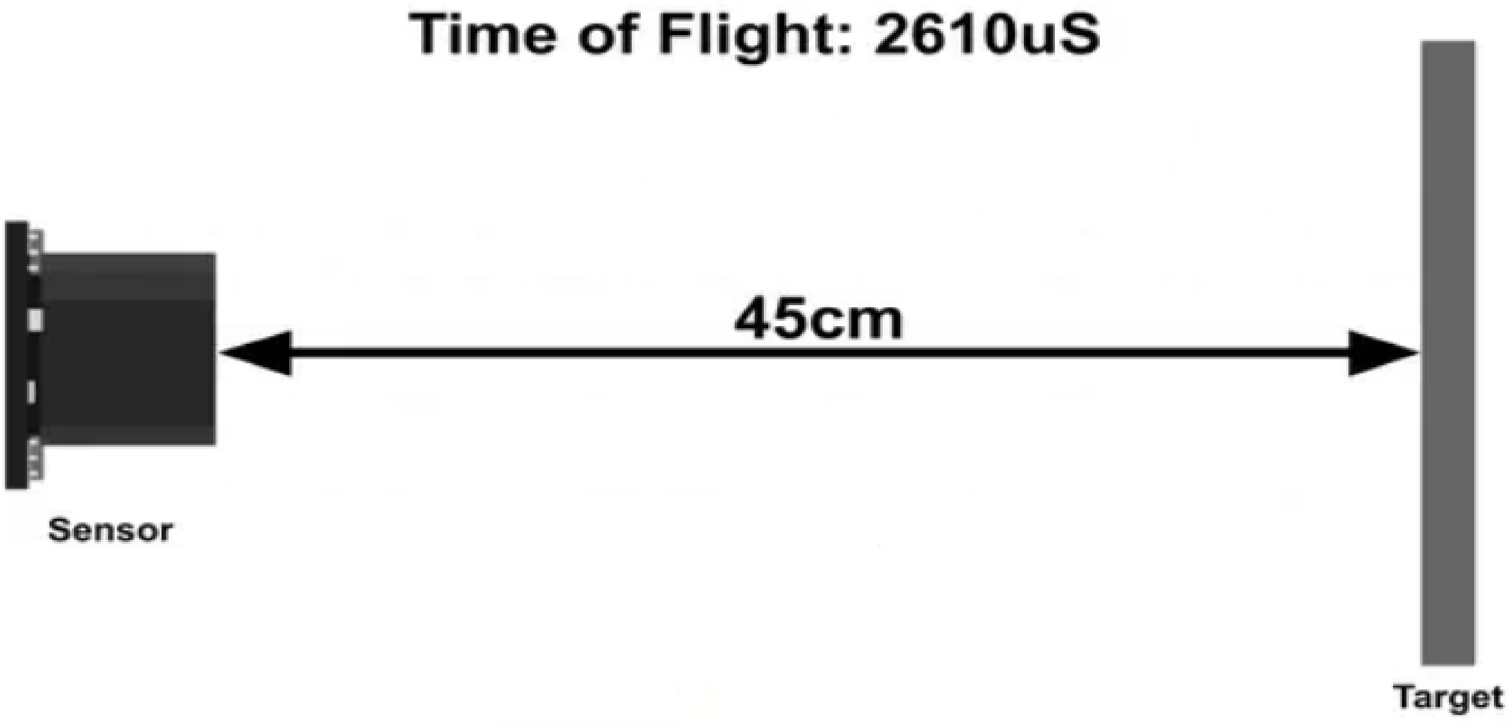
Human Detection Robot Using PIR Sensor

The human detection robot using PIR sensor *mainly detects human*, and it is based on an 8-bit microcontroller.

A passive infrared sensors used to detect the human beings and this project is mainly used to *rescue people stuck in debris during earthquake*. It basically brings humans stuck under debris to the surface, thereby saving them effectively.

2.2 Ultrasonic Sensor

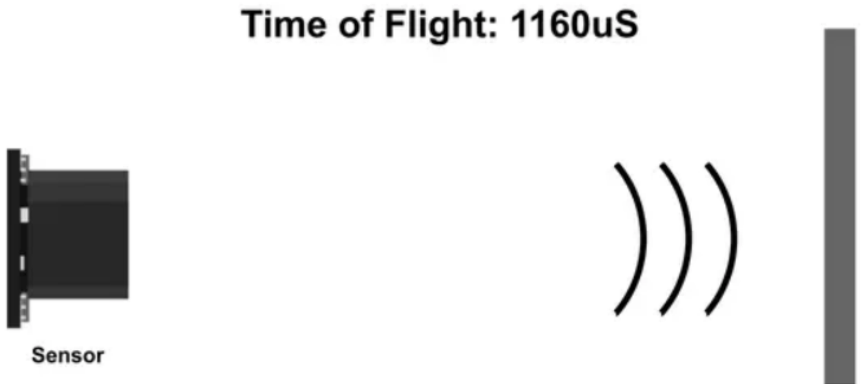
Ultrasonic sensors work based on the principle of *sending and receiving sound waves*, specifically ultrasonic sound waves, to detect objects and measure distances.

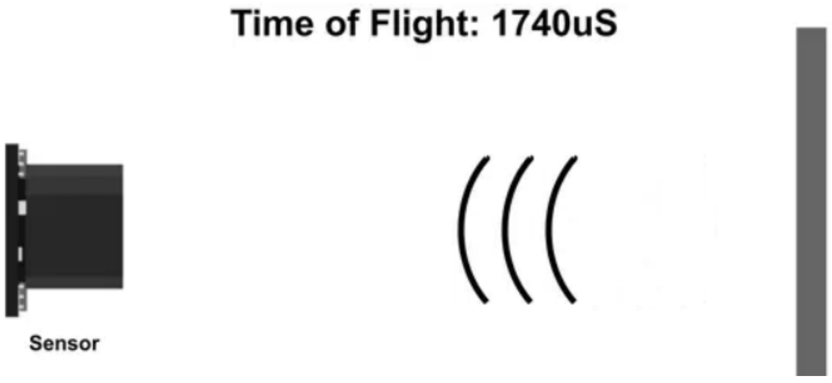


Working Principle

Sound Wave Emission: The ultrasonic sensor's *transmitter emits a burst of ultrasonic sound waves*, which are *inaudible to humans*. These sound waves travel through the air at a specific speed, usually at the *speed of sound*.

Reflection: When these sound waves *encounter an object in their path*, some of the waves are *reflected back towards the sensor*.





Detection: The reflected sound waves are *detected by the sensor's receiver*.

Time Measurement: The *control circuit measures the time* it takes for the sound waves to travel from the transmitter to the object and back to the receiver. This time is often referred to as the "*time of flight*."

$$\text{Distance} = \frac{\text{Speed of Sound} \times \text{Time of Flight}}{2}$$

Distance Calculation: Using the known speed of sound in the air, the sensor calculates the distance to the object by multiplying the time of flight by the speed of sound and then dividing it by two. This is because the sound waves travel to the object and back.

The formula for the distance to the object can be expressed as:

$$d = \frac{v \times t}{2}$$

d = distance from the sensor to the object,

v = speed of sound in air (typically around 343 m/s at 20°C),

t = total time taken for the sound to travel to the object and back.

Temperature Adjustment

The speed of sound in air changes with temperature, so for higher accuracy, we can adjust it using:

$$c = 331.3 + 0.6 \times T$$

T is the temperature in degrees Celsius.

c is the adjusted speed of sound in meters per second.

Output: The calculated distance is provided as an output from the sensor. Depending on the sensor model, the output can be a digital value (e.g., pulse width modulation or serial data) or an analog value (e.g., voltage level proportional to distance).

- **Pulse Width Modulation (PWM):** The sensor emits a pulse where the width of the pulse is proportional to the calculated distance. A *wider pulse indicates a longer distance*, and a shorter pulse indicates a closer object.

- **Voltage Level Proportional to Distance:** The sensor produces a continuous voltage level that changes with distance. For instance, *a closer object might yield a lower voltage*, while a distant object gives a higher voltage, with each voltage corresponding to a specific distance.

Applications:

Distance Measurement: They can measure distances with a high degree of accuracy, making them suitable for applications like object detection, obstacle avoidance, and level measurement.

Object Detection: Ultrasonic sensors can detect the presence or absence of objects, even in the dark, by measuring the distance to the objects.

Proximity Sensors: They are commonly used in robotics, automation, and security systems to determine the proximity of objects or obstacles.

Parking Assistance: Ultrasonic sensors are employed in automotive parking systems to help drivers avoid collisions when parking.

Suppose the TOF for the echo is measured as 10 milliseconds (0.01 seconds), and the ambient temperature is $25^\circ\mathrm{C}$.

Calculate the Speed of Sound:

$$c = 331.3 + (0.6 \times 25) = 346.3\,\mathrm{m/s}$$

Calculate the Distance:

$$\text{Distance} = \frac{346.3\,\mathrm{m/s} \times 0.01\,\mathrm{s}}{2} = 1.7315\,\mathrm{m}$$