

Chapter 1 - Optical Sensors

Sensors are essential elements in an embedded control system because they allow the use of feedback to provide the controller with information on the state of the system it is trying to control (See *Chapter 9 - Control Algorithms* for more information on how this is done). For example, in an automotive cruise control system, there needs to be a way for the controller to determine the car's speed, thereby allowing the controller to *increase* or *decrease* the engine's throttle until the car reaches the desired speed. In the development of the smart car, an optical tracking system is used to sense the lateral position of the car with respect to the optical track which the car is being designed to follow and an optical tachometer is used to measure the car's speed.



Figure 1.1 - View of the white optical track on the track

Infrared LEDs

Infrared LEDs are used in the optical tracking and optical tachometer subsystems of the smart car and are distinct from ordinary visible-light-emitting LEDs in that their operating wavelengths are in the red and near-infrared portions of the electromagnetic frequency spectrum. The infrared LEDs available in the lab operate with a peak emission wavelength of 880 nanometers (*nm*). LEDs that emit light at wavelengths other than 880 *nm* can be obtained for different or more demanding applications.

Infrared LEDs are also available in different physical configurations, thereby providing different viewing angles. The viewing angle determines the region over which the intensity of light emitted by the LED is appreciable. For example, the infrared LED *MLED77* is encased in a plastic package, and light is emitted through the window of a molded plastic lens. This LED has a narrow viewing angle and can be used in sensing applications where the photodetector is on-axis with the emitter. The infrared LED *QED222* is packaged to provide a wider viewing angle and can be used in applications where the photodetector may be off-axis with the emitter.

An optical sensor unit can be constructed by using an infrared LED in conjunction with a matched photodetector. A matched photodetector implies that the photodetector is most sensitive to the wavelength at which the infrared LED operates. The infrared LEDs are preferred to the ordinary LEDs for the following reason. When the infrared LED is used in conjunction with a matched photodetector, the resulting sensor is almost *insensitive* to ambient light. Since the operating wavelength of 880 *nm* falls outside the visible spectrum, ambient light constitutes a negligible source of noise. This obviates the need for elaborate filters to reduce noise caused by the presence of ambient light.

Photodetectors

Electronic light sensors (photodetectors) come in many forms; the most notable of these are photodiodes and phototransistors.

Photodiodes

Diodes, in general, allow current to easily flow in the direction of anode to cathode while having a high resistance to the flow of current in the opposite direction. A small amount of current can pass from cathode to anode in typical diodes. In photodiodes, the amount of this leakage current from cathode to anode is directly proportional to the intensity of the incident light; as the intensity of the incident light increases, more current is induced to pass through the photodiode. Different types of photodiodes are sensitive to different wavelengths of light.

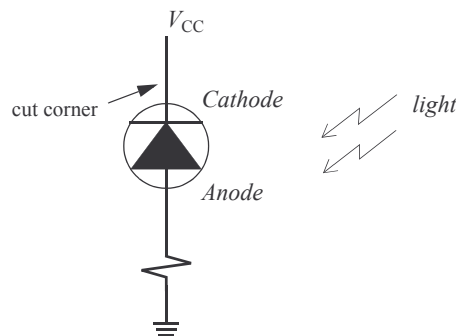


Figure 1.2 - Example photodiode

For the purpose of the optical tracking subsystem, we will be using infrared photodiodes to detect the amount of light from the infrared LEDs that is reflecting off the surface of the track. The configuration shown in *Figure 1.2* will prevent current from the power source flowing to ground when no infrared light is present. As the amount of infrared light increases, the leakage current will also increase. As current flows across the resistor, it produces a voltage that can be used to determine the amount of light incident on the photodetector. The voltage across the resistor can be

acquired by the C8051 through its A/D converter, and with suitable calibration, the C8051 can thereby determine the intensity of light incident upon the photodetector. Due to the small amounts of leakage current, a large resistor is critical in this circuit to obtain a voltage in the range that can be sent to the A/D converter.

The smart car can utilize this principle in sensing its lateral position with respect to the optical track. The digital output from the C8051's on-board A/D converter can be used as a measure of the distance from the edge of the two contrasting reflective surfaces, if the computer program has been calibrated for those surfaces.

The optical sensing units for the smart car will use QSE773 photodiodes, which have a peak sensitivity of 930 nm. The spectral emission of the 880 nm emitters is not ideally matched to that of the 930 nm detectors, but this mismatch can be tolerated in most applications and is justified by the lower cost of the QSE773 photodiodes.

Phototransistors

Phototransistors are transistors in which the base (flat side of the transistor symbol - b) is turned on by the incident light. When the intensity of the incident light is sufficiently high, the base-emitter junction is forward biased, and a current is caused to flow from the collector (c) to the emitter (e) and resistor (R). The magnitude of the current is proportional to the intensity of the incident light.

When this current flows through a resistor, it produces a voltage difference across the resistor. This voltage difference can be measured and used to determine the amount of light incident on the photodetector. A simple light-activated switch application using a phototransistor is demonstrated in Chapter 6, the section on *Phototransistors* on page 73.

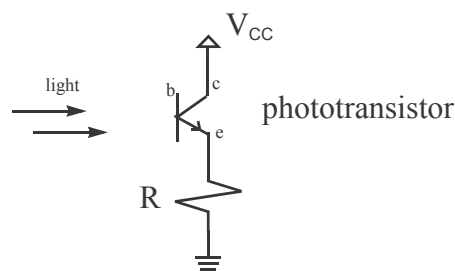


Figure 1.3 - Example phototransistor circuit

Optical Tachometer

A tachometer is a device that is used to measure angular (rotational) speed. In the development of the *Smart Car*, a tachometer is used to measure the speed of the car's drive motor. It is comprised of a codewheel attached to a gear on the drive motor and an optical incremental encoder module containing matched infrared LED and photodiode (see Figure 1.4) which straddle the codewheel

(see Figure 1.5). Similar to how the OTUs detect the optical contrast between the dark floor and the white tape, the optical tachometer detects the optical contrast between spaces (slots) and metal bars on the codewheel. Four photodetectors in the encoder module are spaced such that when one pair are by a space in the codewheel, the other pair are blocked by the adjacent metal bar of the codewheel. The signals from the photodetectors are fed to internal comparator circuits to produce close to a logic output. Two outputs are generated to channels A and B which are 90 degrees out of phase, but only one channel output is needed for the tachometer. This voltage is a logic output (+5v or 0v) due to the comparator circuits in the encoder, and is input to the pulse accumulator to use for tracking speed and distance as described later.

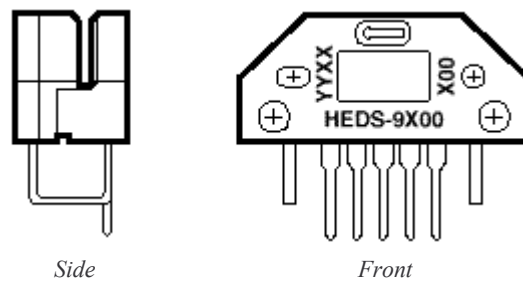


Figure 1.4 - HEDS-9100 optical incremental encoder module for the optical tachometer

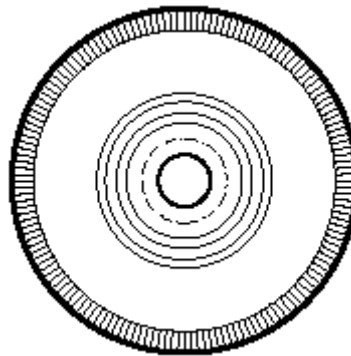


Figure 1.5 - HEDS-5120 codewheel for the optical tachometer

The rotation of the drive motor forces the gear and attached codewheel to rotate at a speed corresponding to that of the drive motor. As the codewheel rotates between the LED and matched phototransistor, a series of pulses due to the passing of the slotted sections of the codewheel are produced by the optical sensor and associated circuitry. The rising or falling edges of these pulses can then be counted by the pulse accumulator and used as a measure of the car's speed and distance traveled.