

Our periodic column for PIC programming enlightenment

The PIR motion sensor

IMAGINE the scenario, you're coming home from work, it's late in the evening and very dark; you can barely see your nose in front of your face. You struggle to get your key in the door and suddenly the light turns on. Your motion activated it as you approached the door – isn't technology wonderful?!

Last month, we talked about beginning the New Year with a fresh start and getting on board with version control, repositories and bug tracking. This month we're going to take a look at motion sensors. These sensors allow us to detect whether a human or an animal has passed in front of the sensor and allow us to perform some action based on this function; for example, turn on a light or set off an alarm. They're used all around us, and many of us have at least one in our home as part of the alarm system. They seem simple enough, but as we're about to find out, they can be complicated and there is some very interesting technology behind how they operate.

Passive infrared

Passive infrared sensors (or PIR sensors) are 'passive' because they do not generate or radiate any energy in order to detect changes in the infrared spectrum. These devices use two infrared sensors, positioned side by side and calibrated to each other, which detect the energy given off by surrounding objects. The two sensors then subtract the different infrared levels measured and output a signal based on this. Take the example of someone walking in front of the sensor pair. One side will measure the ambient background level of radiated

energy and the other side will measure a *changing* level caused by the person. Once the person has passed, both sides of the sensor will be balanced again.

What is infrared?

Infrared is an invisible radiating energy that operates in the electromagnetic spectrum at frequencies between 300GHz and 430THz (or a wavelength of 1mm to 700nm). It is used in industrial, scientific and medical environments. It has been deployed in night vision devices to give the user vision without illuminating the area; in astronomy to gain insight into dusty regions of the cosmos; thermal imaging of overheating in electrical or electronic systems; and observing blood flow in the skin.

The best thing about infrared is that almost all of the thermal radiation emitted by any object, near room temperature, emits this energy in the infrared spectrum. This means that everything in the room emits its own thermal radiation. These emissions are fairly static, but a moving object that emits its own heat signature passing in front of these other objects would cause a change in the emitted radiation that is captured by the IR sensor. It is this change that our motion sensor captures and allows us to detect movement.

The pyroelectric effect

Taking a deeper look inside the physics of infrared sensors, they contain a set of circuits made from pyroelectric materials. These materials generate a voltage depending on the *change* in temperature that they sense. The *change* in temperature causes excitation of the atoms within the

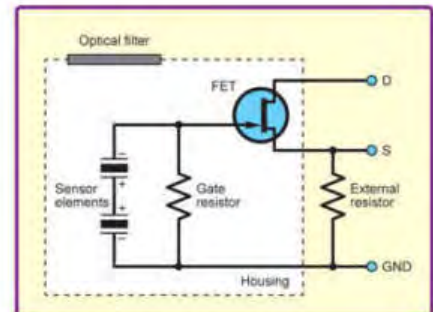


Fig.2. Basic PIR circuit diagram

material's crystal structure, which in turn causes polarisation of the material – this induces a voltage across the crystal. If the temperature stays at this new level, then the voltage will gradually disappear (through current leakage and other effects). So, if a person moving in front of the sensor stops moving then the temperature change and induced voltage will decay. However, if the temperature keeps changing, the voltage will continually be applied (for example, constant movement in front of the sensor). When the sensor is exposed to an infrared radiation change, the induced voltage results in a surface charge. As this radiation changes, so does the charge. A FET is used to buffer this potential. To convert the FET current to a voltage, an external resistor is added (roughly 100kΩ) as seen in Figure 2.

Various materials are used in PIR sensors; for example, gallium nitride (GaN), caesium nitrate (CsNO₃), polyvinyl fluorides, derivatives of phenylpyridine, and cobalt phthalocyanine. Lithium tantalate (LiTaO₃) is a crystal that exhibits both piezoelectric and pyroelectric properties. Lithium tantalate has proven useful for various applications including terahertz generation and detection, cell phones and even pyroelectric nuclear fusion.

Lenses

The sensors themselves have very limited range, typically only a few centimetres. However, the addition of a lens, can increase this up to 30 meters. The specific lens type used for PIR motion sensors are known as 'Fresnel lenses' (see Fig.1b). These lenses are 'plano-convex' (one side of

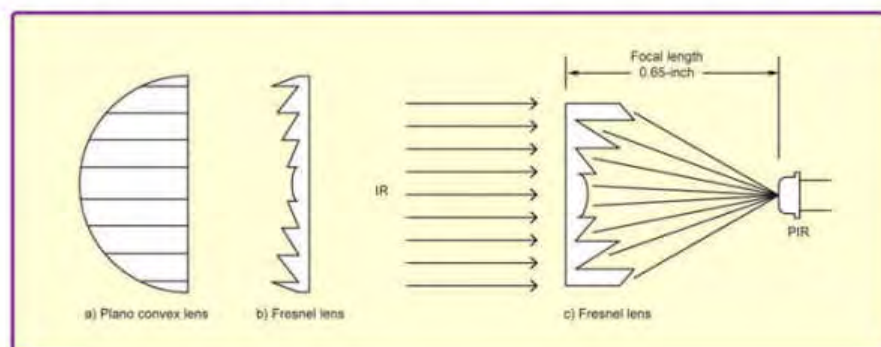


Fig.1. Plano-convex and Fresnel lens

the lens is flat, the other side is convex, see Fig.1a) that have been collapsed in on themselves, while still maintaining their optical characteristics. The FL65 Fresnel lens is one such lens that is ideal for use in PIR motion sensors. It is 1.5-in square, has a focal length of 0.65-in and has a 10-degree field of view. This specific lens comprises an infrared transmitting material with an IR transmission range of 8 to 14 μ m (micrometre), making it the most sensitive to human body radiation, which is roughly 10 μ m in wavelength. Fig.1c shows the infrared radiation as it hits the Fresnel lens and how it is focused onto the PIR sensor with respect to its focal length.

You may well have seen Fresnel lenses as a plastic, ribbed sheets used for cheap, but flexible magnifying lenses. They are also commonly used in lighthouses and can be as big as 3700mm in diameter, such as in the Makapuu Point Light in Hawaii, which uses over a thousand prisms to form its lenses (see: <http://tinyurl.com/nssg5hg>). Their big advantage is they can focus light without using huge volumes and masses of glass.

Which PIR motion sensors to use?

There's quite a number of PIR motion sensors on the market available from Adafruit, Sparkfun, Farnell and eBay. Each of these have their own unique advantages and disadvantages. This is where it can become a bit of a minefield, as I found out when researching this article. Learning more about the technology and understanding exactly what we want is of course beneficial. We need something that allows us to detect motion up to a couple of metres away, and also we want some sort of signal that a microcontroller like our PIC18F can easily discern as an 'event'. Once we detect this event, we can make a decision on what the next course of action is – for example, sound an alarm, turn on a light or open/lock a door.

Analogue versus digital Sensors

Starting off with the most basic motion sensor, we have the analogue dual-element sensor. Some examples are the LHi 968 from Excelitas Tech, the IRA-E710ST0 from Murata and the RE200B. These are the fundamental parts of the PIR sensor itself. They each have two elements, which monitor the incoming IR radiation. If a difference is detected between the two sensors, then the FET is turned on and an output signal is seen. The sensors are constructed from pyroelectric sensor elements connected to the gate of a FET. When a difference in IR radiation is seen across the two sensor elements, a voltage is produced and the FET is turned on, producing our signal on the output (see Fig.2).

Just to be clear, by 'analogue' sensors, I mean the bare-bones



Fig.3. Analogue versus digital output

pyroelectric sensor with no extra circuitry. The main difference between analogue and their close relation the 'digital' sensor is the type of output signal. Analogue sensors output a nominal voltage during normal operation and will change this voltage by a certain amount based on the detected IR difference in the sensor. This difference in voltage is usually quite low, in the range of 10-15mV peak to peak. The top oscilloscope capture in Fig.3 shows the signal we're dealing with here. It is possible to connect these straight up to a PIC and use an ADC pin to measure the nominal, at-rest voltage value. Then, anything outside this normal range can be a triggered event. Unfortunately, the output can be quite noisy and discerning between noise and a valid response can be difficult and inaccurate. Our ADCs are usually only 10 bits, giving us a resolution of 3.2mV (3.3V divided by 1024 bits), using a supply voltage of 3.3V. This gives us about 5 bits of difference, which really isn't much to work with. This can be used as a simple circuit, but it is very sensitive



Fig.4. The EKMC1601113 digital output PIR sensor from Panasonic Electric Works

and can trigger on even the slightest temperature change in a room. While this is a valid solution, I would like to improve on this, which means we will need to add more circuitry to clean up and amplify this signal.

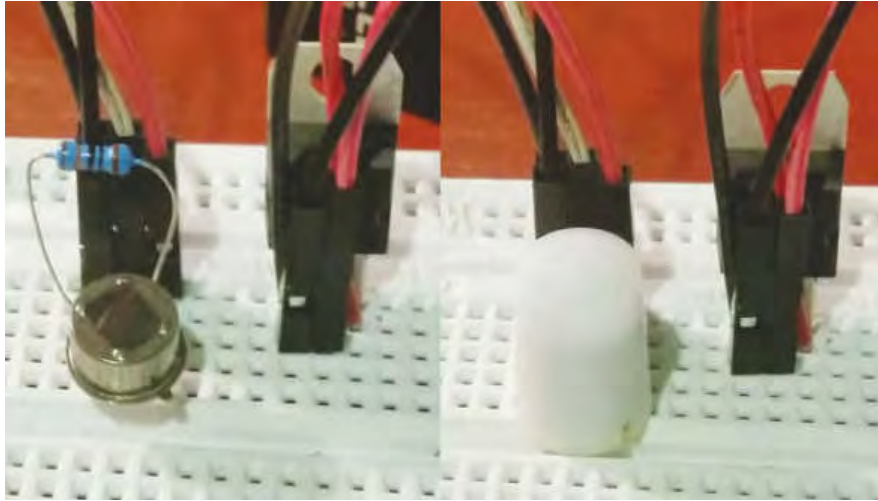
With a digital sensor, we are given a clean digital output that is high when motion has been detected and low when it is at rest. This is exactly what we want. The EKMC1601113 from Panasonic Electric Works is one such digital signal output motion sensor (see Fig.4). It is a fully integrated PIR motion sensor, which contains our Fresnel lens, giving us up to 5m of detection range, as well as containing all of our embedded amplifiers and comparators to give us a beautiful digital output, seen in the bottom oscilloscope capture in Fig.3 (this sensor is also lead free as it is constructed with lithium tantalate, mentioned above). Most of the digital sensors come in at around £7, while the analogue sensors can cost as low as £1.69.

In Fig.5, we have a basic comparison of the Analogue LHi968 and the Digital EKMC1601113. There is only an external 100k Ω resistor on the LHi968 circuit and the output from this can be seen in the top oscilloscope trace in Fig.3. The output from the EKMC1601113 contains no external circuitry and can be seen in the bottom oscilloscope trace in Fig.3. The package sizes are very close in size, but the difference in functionality is huge, from a range of a few centimetres to 5m in the integrated sensor and an easy-to-see output, the digital sensor is clearly a winner.

Wrapping it all up

We've had a look at just a small number of the motion sensors available to us and how they operate. As we compare analogue versus digital output sensors, we might wonder why choose one over the other. The digital output sensor seems like the obvious choice. It is more expensive because it contains all the necessary system components (Fresnel lens, amplification, buffer and comparator circuits), but its drawback lies in the fact we cannot customise it. Each one is specifically designed for one purpose. However, Sparkfun offer a bulkier version, which allows the user to tune the sensitivity of the sensor and the delay time between triggered events.

There is something to be said for building your own circuit and tuning it yourself using one of the analogue motion sensors described above, plus it is a lot more fun! For a quick design guide to get you started, check out the GLOLABS website (www.glolab.com/index.html). You can find a few interesting projects to help you build your own pyroelectric circuits and go beyond to building direction sensing motion detectors as well.



Next month

Now we've covered some basic motion detection, how about some very small motion detection using an accelerometer and some haptic feedback. Next month, we're going to take a look at how three-axis motion detection in an accelerometer works, what we can do with it and how we can recognise a gesture in a handheld circuit and in turn drive a haptic response. And of course we will start to look at connecting these devices to a PIC.

Fig.5. Analogue and digital motion sensor circuits.

Not all of Mike's technology tinkering and discussion makes it to print. You can follow the rest of it on Twitter at [@MikePOKeeffe](https://twitter.com/MikePOKeeffe), up on EPE Chat Zone as [mikepokeeffe](https://www.epechatzone.com/mikepokeeffe) and from his blog at mikepokeeffe.blogspot.com