You have to connect a sensor, which does not come with the chip. We've found copper mesh or copper foil works nicely as the sensor. The connection between the sensor chip and the sensor itself also reacts to changes in capacitance, so you'll find that even touching the wire between the two will trigger a reaction. This can be a problem if you only want a very localized area to be sensitive, or if the sensor wire has to run near other current-carrying wires. To get around this, use a shielded conductor between the chip and the sensor. A *shielded conductor* is a wire or a group of wires wrapped in a foil or mesh wrapping. Many video and speaker cables and computer cables are shielded. If you strip back the outer insulation jacket of these cables, you'll find the foil or mesh wrapping surrounding the inner wires. Don't remove it. Connect it to the ground of your circuit to make the conductors insensitive to capacitive changes.

The important pins on this chip are power and ground, the sense pins, and the output. You can use either of the sense pins for your sensor, then put a capacitor in between them, as shown in the schematic in Figure 11.3. The option pins on the Qtouch ICs allow you to set various options like the sensitivity, the reset time (how long the sensor takes to go low again if no change is detected), and more. Read the data sheet for all the options.

Quantum makes a whole family of these chips (http://www.qprox.com) with various options, including having multiple switches per chip. They also make a few analog capacitance sensors, like the QT300, which give you a changing value when they detect movement within a centimeter or so of the sensor.

Off-the-Shelf Touch Interfaces

Touch screens are the easiest way to connect touch with computer graphics. There are many suppliers that integrate touch screens into ordinary monitors at increasingly affordable prices. In addition to the usual video connection these will have a serial or USB connection for the touch information. After you install the drivers, your software can get the touch location by simply reading the mouse coordinates. You can also buy screens that can be attached to conventional monitors. Elo TouchSystems (http://www.elotouch.com) makes a number of both integrated touch screen monitors and add-on touch screens. You can usually find these in surplus at very reasonable prices. All Electronics (http://www.allcorp.com) frequently has a number of different models in stock. You may even consider using these as sensitive touch panels without attaching them to a monitor.

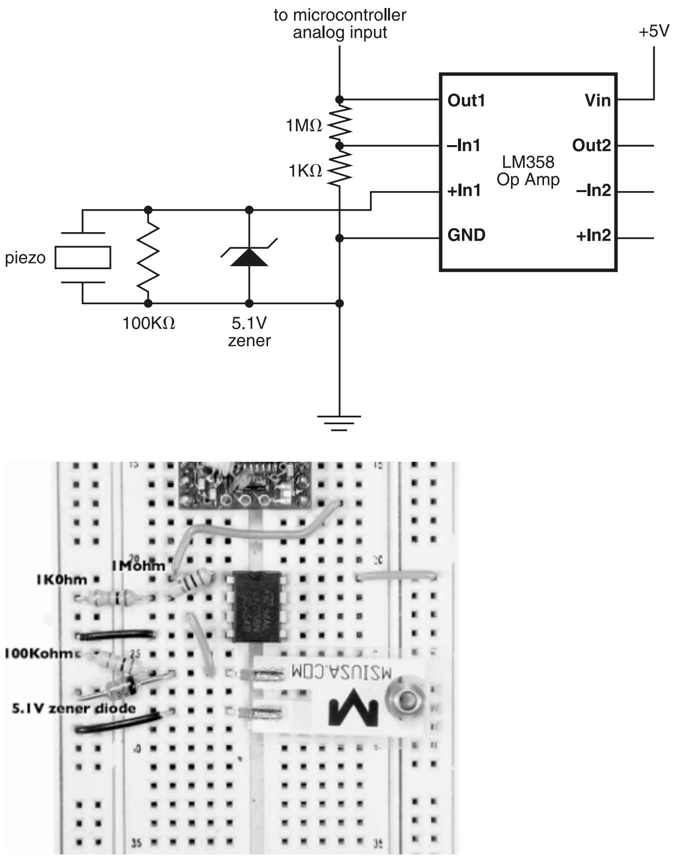
The disadvantage of touch screens is that they generally will only read contact at one point at a time. This means that if you put all five fingertips on the screen, you won't get five discrete locations. Instead, the screen will report several different locations in succession in an inconsistent order. If you want a multitouch touchpad, your options are more limited. Tactex Systems made a wonderful multitouch sensor board, the MTCExpress, but it has been discontinued. Used models show up on eBay frequently and are coveted by musicians.

Sensing Vibrations Using Piezoelectric Sensors

Piezoelectric sensors are often used to detect strain or very slight force changes. These sensors produce a varying voltage when they are bent. They respond very quickly, and to slight changes. Microphones are made of piezoelectric film. In fact, if you connected a piezo to the microphone amplifier circuit in Chapter 13, "Controlling Sound and Light," it would work well as a knock detector. With a fast processor like a PIC, you could use two piezos on a table and time the arrival of their signals to determine the position of a knock on the table. Piezos are used for all kinds of sensors beyond microphones, from sensing strain on bridges to the hitting of a drum to the pitter-patter of children's footsteps in flashing sneakers.

The voltage range that a piezo sensor can produce can be up to a few thousand volts, and it can generate changes as small as a few microvolts. Because of this, piezos can be difficult to read across their entire sensitivity range. One common way to read miniscule changes from a piezo is to use an *operational amplifier*, or *op amp*. Op amps take a very small voltage signal and amplify it to a range that's readable. They can be used for many other functions as well, like reading the difference between two voltages, the sum of two voltages, and more. They've got a reputation among physical computing hobbyists for being difficult to use, but they don't have to be.[1] Figure 11.4 shows one very simple-to-use op amp used to measure the changes from a piezo.

Figure 11.4
A piezo sensor and an LM358 op amp to amplify the voltage changes.



[1] There's much more to be said about op amps. For a more lengthy and technical introduction, see *Practical Electronics for Inventors* by Paul Scherz (McGraw-Hill/TAB Electronics, 2000). If you're really itching to dive into the subject in depth, see *The IC Op Amp Cookbook* by Walter C. Jung (Prentice Hall PTR, 1986).

This op amp, the LM358, is called a *single-supply* op amp because it only needs a positive voltage and ground. Many op amps are *dual-supply*, meaning that they need a positive voltage, ground, and a negative voltage. The output from this circuit will vary between 0 and 5 volts, depending on your piezo and what it's physically mounted to. You can read it with an analog-to-digital converter. If you're using the BS-2, you'll find that the RCTime circuit doesn't catch all the changes from this circuit because the piezo changes voltages very fast. The more extreme the piezo is bent, the more voltage it will produce.

The sensor in the circuit in Figure 11.4 is a piezo film sensor with vibrating mass from Measurement Specialties (http://www.msiusa.com/sensors). It's available from many other suppliers, including Digi-Key as part number MSP-1007-ND. You can use almost any piezo element, though. A piezo speaker cut out of a child's toy used with the same circuit is sensitive enough to respond to a very delicate touch, even to blowing.

You can change the amplification factor of the op amp by changing the two resistors attached to the negative input pin. In this circuit, they're 1 kilohm and 1 megohm, giving an amplification of 1000:1.

The unusual diode attached to the piezo is called a *zener diode*. You'll see it again in Chapter 13, when you build a telephone line interface. A zener diode allows electrical energy to pass up to a certain voltage and cuts the rest off. In this circuit, the zener diode is rated for 5.1 volts, and it's used to send to ground any voltage that the piezo produces above 5 volts.

Creating Vibrations

The most common method of creating vibration is to put a weight off center on the shaft of a motor and spin the motor. You can easily build this by crimping a fishing weight on to any DC motor, or you can hack open a massaging vibrator. You can also find surplus supplies of tiny vibrating motors used in cell phones and pagers. Jameco Digi-Key, All Electronics, and others carry these. They work great in any application where they're positioned near the body. We've seen them put in hat bands, money belts, and many other clothing items as a way to give the wearer an alert without calling attention visually or aurally. Solarbotics (http://www.solarbotics.com) sells them without the weights, so you can use them as regular motors as well, though they're not very powerful. Controlling them is no different than any other DC motor (see Chapter 10). Most of them run on about 1.5 volts, so make sure you're using a supply that doesn't provide more voltage than they can handle.

Taking Your Temperature

A byproduct of human touch is heat. You can determine if someone is touching an object by detecting an increase in heat using a thermistor. Thermistors convert heat into electrical resistance. They are easy to find, cheap, and they plug easily into the standard analog input circuit. Changes in ambient heat conditions can throw off your readings, so it is important to also have a control thermistor to measure current ambient conditions for comparison. Heat does not dissipate as quickly as light, so your readings may seem a little slow in changing. For this same reason you can tell a little bit about how long something has been touched by how warm it has become. We mention thermistors here because heat