Building Sensors for the Programmable Brick

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This article explains how to build a variety of common sensors for use with the MIT Programmable Brick. Some of these sensors replicate the functionality of existing LEGO sensors (e.g., the touch sensor), but others add new capabilities altogether (e.g., the differential light sensor and the bend sensor).

The article begins with an overview of electronic construction technique and part-buying, and then presents the designs of the sensors. Plans for three different types of sensors are included:

- touch sensors
- light sensors
- bend sensor

Though the focus of the article is providing practical design plans for building the various sensor devices, a bit of an explanation of how they work is presented.

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1 Construction Hints

Throughout this article, references to Radio Shack catalog numbers are provided for the various tools, supplies, and components. Radio Shack is by no means the only supplier of these materials, but they are a convenient one, and their prices are generally reasonable.

If setting up an electronics workshop from scratch, I recommend obtaining a catalog from MCM Electronics (650 Congress Park Drive; Centerville, OH 45459; 800–543–4330). They are a highly reputable distributor with an extensive assortment of good quality tools and accessories at prices 30–50% less than Radio Shack.

1.1 Tools

The tools required for building the Programmable Brick sensors are:

Soldering Iron A small pencil-style soldering iron, rated at 15 to 30 watts, is fine for this work. Any soldering iron intended for electronics use is acceptable (e.g., Radio Shack 64–2051, $7.49). Don't use large irons that are intended for heavy-duty industrial use (e.g., for pipe welding).

Solder A light gauge rosin-core solder intended for electronics work is recommended (Radio Shack 64–005, $3.49). Do not use acid flux or other types of solder.

Hand Tools Several hand tools are necessary: a *wire stripper* for removing the insulation from wires, a *long-nose pliers* (Radio Shack 64–1812, $6.99) for crimping joints together before soldering, and a *diagonal cutters* (Radio Shack 64–1813, $6.99 or 64–1833, $3.99) for clipping joints after they have been soldered.

Additionally, the *helping hands* tool (Radio Shack 64–2094, $4.49), which is a pair of alligator clips mounted on flexible arms, is useful for holding parts together while the soldering iron is in hand.

(For beginning electronics, Radio Shack sells a package of most of the hand tools, a soldering iron, and solder, catalog number 64–2801, for $17.99.)

Multi-tester A simple "VOM meter" (volt-ohm meter) or digital multimeter will be extremely useful in checking continuity of cables and measuring resistance values. A decent low-cost model is the Radio Shack 22-169, $27.99.

Hot Glue Gun A craft-store hot glue gun is ideal for "LEGOizing" the sensors (attaching the sensor electronics to a LEGO brick for ease of mounting).

Safety Glasses I personally urge the use of eye protection when soldering. Burning hot, molten droplets of solder can easily flick off of the iron tip and fly through the air. I've had these land on my cheek on occasion. Wearing safety glasses is the only way to protect the eyes.

1.2 Parts

Most of the sensors may be wired the 9-volt LEGO connector, a 2×2 LEGO piece with a two-wire connection. Sensors wired to the LEGO connector be used with both the Programmable Brick *and* LEGO Control Lab, an added benefit for users of both of these systems.

All of the sensor designs may be wired to the *stereo mini-plug* connector, which is specific to the Programmable Brick. This is the connector commonly found on headphones used with personal cassette players.

Plans are provided for wiring sensors to both types of connector when possible. In classrooms that already have a supply of stock LEGO sensors, I recommend building additional sensors for the Programmable Brick using the stereo mini-plug connector because each Brick can support three of each type of sensor, so it's good to have an assortment of both types.

1.3 Technique

1.3.1 LEGO Connector

When building the LEGO-compatible sensors, it is necessary to purchase additional LEGO jumper cables and cut them in half. Each cable half yields one connector, with a stretch of wire already provided.

The twin-wire cable that LEGO uses with its jumper cables does not easily "zip", or separate into single threads. It is necessary to use diagonal cutters to

(2$\times$ normal size)

Figure 1: $\frac{1}{8}$ Inch Stereo Mini Plug Diagram

When building the mini-plug sensors, a good idea is to buy a mini-plug-to-mini-plug cable and cut it in half, just like the technique with the LEGO connectors.

Radio Shack 42–2387 is the proper cable. If you prefer to use your own wire and connect to hobby stereo mini-plugs, use Radio Shack 274–284 (3 conductor 1/8" plug).

When wiring the mini-plug sensors, it is necessary to connect specifically to the tip, ring, or base of the connector (Figure 1). After cutting the cable in half, use the multitester to determine which wires connect to which positions on the plug.

Sometimes the internal wiring of such cables changes between manufacturing production runs, so it is prudent to check each cable before wiring to it. For example, on one cable you may determine that the red wire goes to the tip, the white wire to the ring, and the black wire to the base. But if you buy the same cable six months later, the red and white wires may be swapped! Cable manufacturers don't expect you to be cutting the cables open, so they're not compelled to use the same color-coding scheme every time they gear up the factory.

1.3.3 LEGOizing the Sensor

After wiring the sensor and determining that it is functional, you may with to "LEGOize" the sensor—that is, glue it to a small LEGO brick so that it may be easily mounted on your LEGO models.

The hot glue gun is great for this type of gluing. Be careful not to get the hot glue on your fingers when applying, because it’s both hot and sticky—a nasty combination.

Figure 2: Microswitch Touch Sensor with Mini-Plug

Figure 2 shows the circuit for a microswitch-type touch sensor with a mini-plug connector. The touch sensor returns a value of “true” when the switch leaf is depressed.

This circuit shows how to wire a three-terminal switch, known to electrical engineers as an SPDT, or single-pole, double-throw switch (e.g., Radio Shack 275–016, $1.99). This type of switch has one pole terminal, the common (C) terminal, that is connected to the normally closed (NC) terminal when the switch is resting. When the switch is depressed, the connection to the NC terminal is broken, and instead closure between the (C) terminal and the normally open (NO) terminal is made.

When the sensor is wired as shown, it will return a value of near 255 in the resting state and near 0 when pressed. Use a comparison like “`sensorf < 100`” to indicate true when the switch is pressed.

Figure 3: Pushbutton Touch Sensor with Mini-Plug

Figure 3 shows the circuit for a pushbutton-type touch sensor with a mini-plug connector. The touch sensor returns a value of "true" when the switch button is depressed.

This circuit shows how to wire a two-terminal pushbutton switch. The "normally open" type of pushbutton (e.g., Radio Shack 275–1571, two for $2.39) should be used. When the switch button is depressed, the two terminals are connected together.

When the sensor is wired as shown, it will return a value of near 255 in the resting state and near 0 when pressed. Use a comparison like "`sensorf < 100`" to indicate true when the switch is pressed.

The value of the resistor is not significant within the range indicated.

Figure 4: Microswitch Touch Sensor with LEGO Plug

Figure 4 shows the circuit for a microswitch-type touch sensor with a LEGO connector. The touch sensor returns a value of “true” when the switch button is depressed.

This circuit shows how to wire an SPDT microswitch to act as a two-terminal pushbutton switch. A simple pushbutton switch (e.g., Figure 3) could be substituted.

A touch sensor connected to the LEGO sensor inputs should be used with the “switch” primitives: e.g., `switcha`, `switchb`, or `switchc`.

Figure 5: Photocell Light Sensor with Mini-Plug

Figure 5 shows the circuit for a simple light sensor using the mini-plug connector. The light sensor indicates the absolute value of light received by a photocell light detector.

Use any available photocell (e.g., Radio Shack 276–1657, five for $2.29), but you will need to measure its resistance to find a proper matching resistor. Measure the resistance in normal room lighting and choose a resistor that has approximately the same value, as indicated in the figure.

To make the photocell directional, build a shield from some opaque material (e.g., LEGO bricks or black construction paper) in front of the sensor element.

The sensor will return smaller values when detecting increasing amount of light—an inverse relationship with respect to brightness.

Figure 6: Photocell Light Sensor with LEGO Plug

Figure 6 shows the circuit for a simple light sensor using the 9-volt LEGO connector. The light sensor indicates the absolute value of light received by a photocell light detector.

Use any available photocell (e.g., Radio Shack 276–1657, five for $2.29), and the resistor specified in the schematic diagram.

To make the photocell directional, build a shield from some opaque material (e.g., LEGO bricks or black construction paper) in front of the sensor element.

The sensor will return smaller values when detecting increasing amount of light—an inverse relationship with respect to brightness.

Figure 7: Differential Light Sensor with Mini-Plug

Figure 7 shows the circuit for a “differential” light sensor with a mini-plug connector. The differential light sensor indicates the degree of disparity in light levels sensed by the two photocell elements.

Use matched pairs of photocells of the same type. For example, if using photocells from the Radio Shack assortment (276–1657, five for $2.29), pick two that have the same physical appearance (size and shape), and check using the multimeter that both have approximately the same resistance when under equal illumination.

The sensor should return a mid-range value (i.e., 128) when both photocells are receiving equal illumination. When the photocell corresponding to the upper one in the schematic is receiving more light, the value will increase, and when the lower photocell is receive more light the value will decrease. In this way the differential light sensor can locate a source of light. Note that it cannot indicate an absolute amount of light.

To maximize the directionality of the sensor, mount a “nose” of opaque material (LEGO or dark paper) between the two photocells, and shield the photocells from ambient light from above and below.

Figure 8: Bend Sensor with Mini-Plug

Figure 8 shows the circuit for a bend sensor with a mini-plug connector. The bend sensor returns a value corresponding to how much the flexible bend-sensitive strip is bent.

In the circuit, the bend sensor is a simple resistive device. The output signal is proportional to the ratio of the resistances of the bend sensor and the fixed resistor.

Be very careful when soldering to the bend sensor! It is very easy to overhead the element and cause it to fail.

Bend sensors were used in the Nintendo PowerGlove as sensor to determine how much the user's fingers were bent when in the glove. Unfortunately they are now out of production and only a limited supply of them remains. I am currently looking for alternate sourcing of the device.

The sensor should return a value near 140 in the resting state, with increasing values as the sensor is flexed. The sensor only detects bends when the printed side is folded on the outside.