Lego Ultrasonic PROXIMITY SENSOR

by Robert Penfold

IN A PREVIOUS ARTICLE ROBERT PENFOLD DESCRIBED A SIMPLE ULTRASONIC REMOTE CONTROL UNIT FOR USE WITH ROBOTS CONSTRUCTED USING LEGO'S POPULAR MINDSTORMS CONSTRUCTION KITS. THE PROJECT FEATURED HERE IS ANOTHER ULTRASONIC DEVICE FOR USE WITH ROBOTS CONSTRUCTED USING A MINDSTORMS KIT, THIS UNIT IS A PROXIMITY SENSOR.

Vehicles built using one of these kits can use the touch sensors to detect collisions, but it is clearly better if a robot can avoid things in the first place rather than running into them and then taking remedial action. The standard Lego light sensor can be used as a proximity detector, and it can work quite well in this application. However, its effectiveness in this role inevitably depends on the reflectivity of the objects that come into its field of view.

An ultrasonic sensor is generally more reliable than a light type in this application. Some objects reflect sound waves better than others, but practically any solid object will reflect the sound well enough to give a good operating range. Ultrasonic sensors are not good at detecting objects that largely consist of empty space, such as a wire fence, or very small objects.

The same is also true of light sensors though, and something more than a very simple sensor is needed for awkward objects such as these. Both light and ultrasonic sensors are highly directional, and operate best when they are perpendicular to the surface being detected. The range of this sensor is therefore reduced when it is at a shallow angle to the target surface, but it should still detect it in time to avoid a collision.

Of course, this sensor is not restricted to operation in robot vehicles. It can also be used as a proximity detector in a stationary robot. In other words, the sensor is used to detect when someone comes close to the robot, and the robot then goes through a routine of some kind. It can also be used to provide the opposite action, with the robot being brought to a halt when someone is detected. Systems of this type are often used with 'real' robots as a safety measure. With a MindStorms kit a proximity detector is probably of most use with toys and novelty devices.

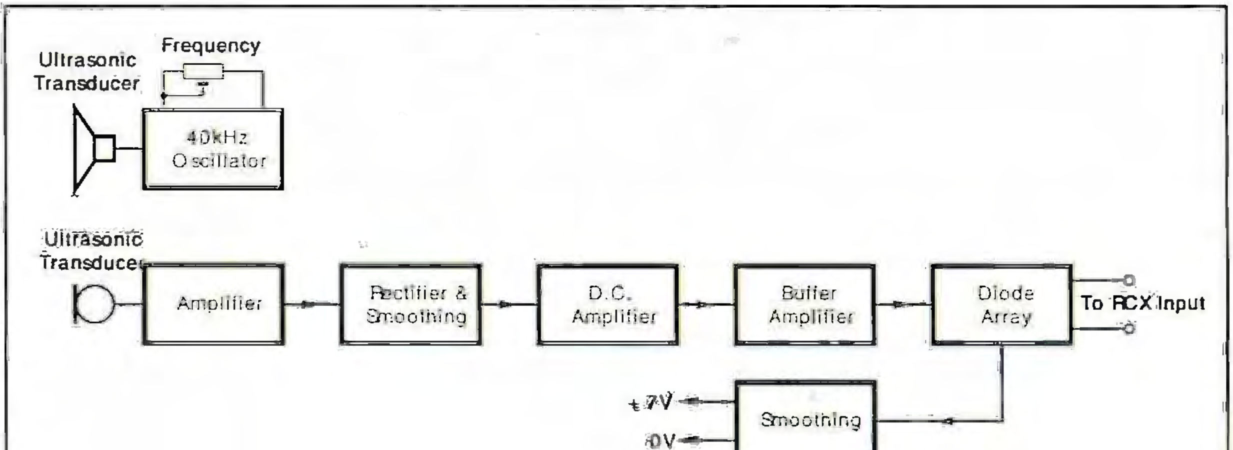


Figure 1.

Range

It is possible to obtain relatively long operating ranges using an ultrasonic sensor. In fact it is possible to obtain detection ranges that are too great for usable operation in average size rooms. With operation at high sensitivity the sensor nearly always detects something, giving unusable results. The range of this sensor has therefore been kept quite short so that it can be used successfully in rooms of normal dimensions. It will still detect large flat surfaces at ranges of around much larger than the 'proper' Lego sensors such as the light and touch varieties. This is due to the relatively large size of the ultrasonic transducers and the need to have the transmitting and receiving transducers a few centimetres apart. Normal vehicle robots still easily accommodate the unit.

System Operation

Figure 1 shows the block diagram for the ultrasonic sensor. The sensor relies on the fact that ultrasonic sound waves are highly range. Only 40kHz types are readily available, and it 40kHz transducers that are used in this design.

Even with a suitable target object well within the range of the unit the output signal from the receiving transducer will be no more than a few millivolts. The receiving transducer therefore feeds into an amplifier stage that boosts the signal to a more useful level. A rectifier and smoothing circuit processes the output signal from the amplifier stage to produce a positive d.c.

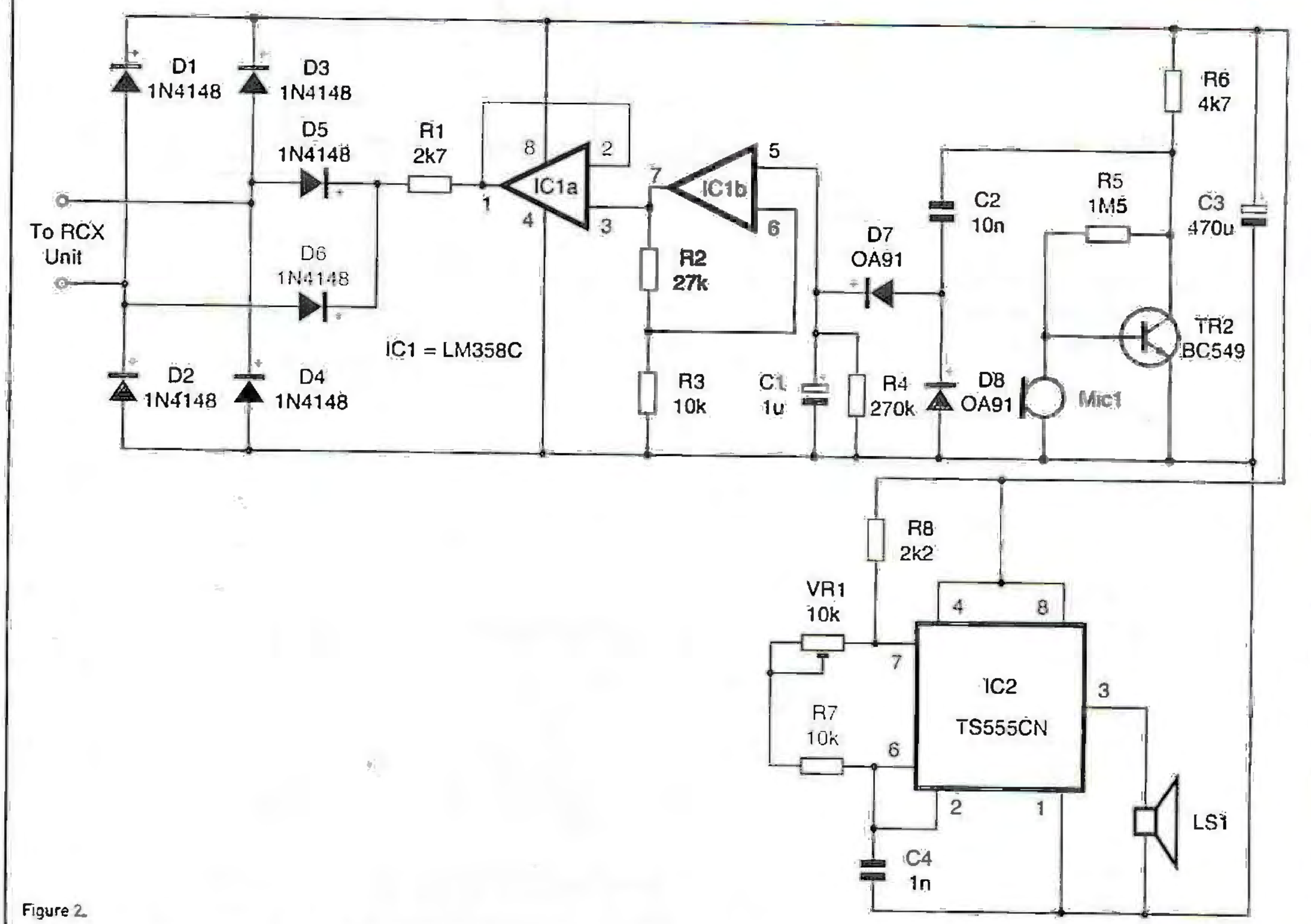


Figure 2.

two metres or so when adjusted for optimum performance. If required, lower sensitivity can be obtained by slightly detuning the transmitter.

The circuit is powered from the RCX unit, and it connects to one of the RCX unit's input ports just like one of the standard Lego sensors. There is no specific support for an ultrasonic sensor in RCX code or any of the other programming languages normally used with the MindStorms kits, but this sensor 'looks' like a normal active sensor to the RCX unit. It can therefore be handled in the software in the same basic fashion as a standard active sensor such as the Lego light type. A sensor of this type is necessarily directional. A continuous signal is emitted by the transmitting transducer, and with a suitable object a couple of metres or less in front of the unit, a reasonably strong signal will be reflected back to the receiving sensor. Although the transmitting and receiving transducers are only about 50 millimetres apart, the highly directional nature of ultrasonic sound waves ensures that direct pickup from the transmitter to the receiver is insignificant. Although one might expect a strong signal to be coupled from one transducer to the other through the case, in practice this does not give any problems either. The transducers are Piezo devices that are only efficient over a narrow frequency signal that is roughly proportional to the amplitude of the received signal. This signal receives a small amount of amplification and it is then fed to the input of the RCX unit via a buffer amplifier and a diode array. The input ports of the RCX unit feed into a 10-bit analogue-to-digital converter. On the face of it, the reading from the converter will give an indication of the target object's range. In practice the reading will vary substantially depending on the efficiency with which the target object reflects the ultrasonic sound from the transmitter. Also, objects less than about one metre from the sensor tend to give the maximum reading. The sensor merely indicates the presence of a target object and

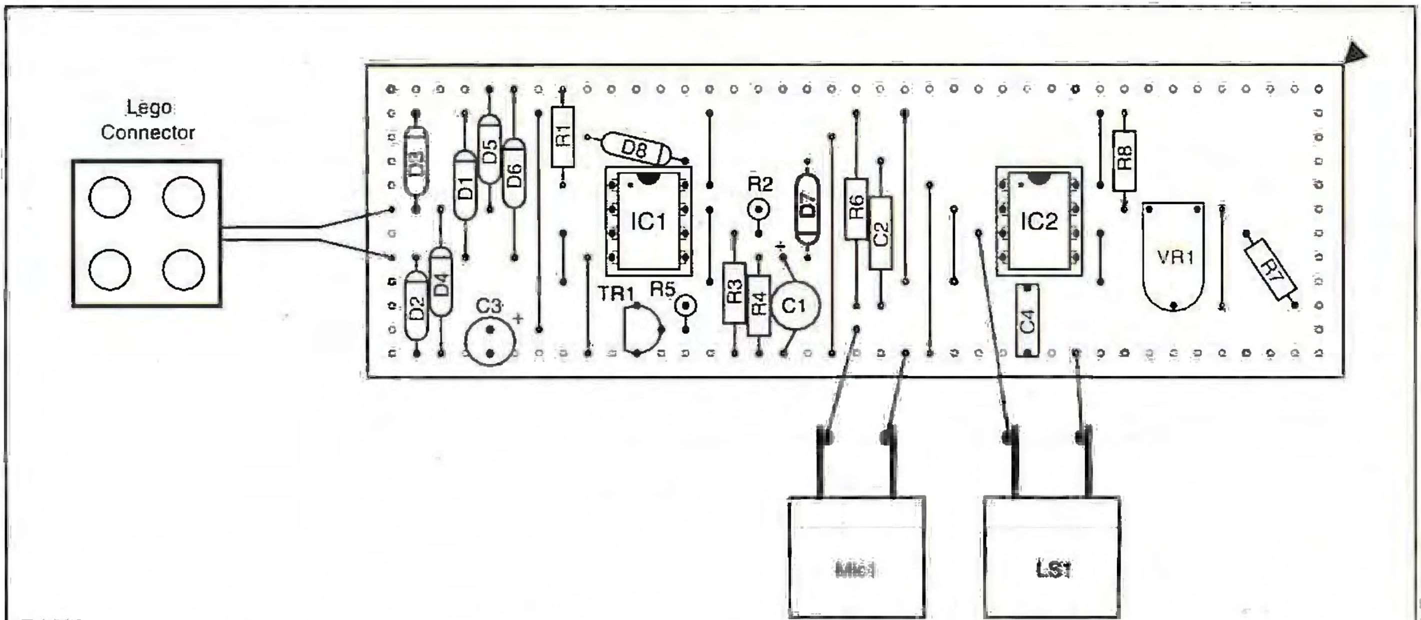


Figure 3.

does not provide a useful range data, but this is adequate for most purposes.

The diode array is needed because of the way in which the RCX unit uses the two input terminals to also act as a power source. The general scheme of things is to have the terminals act as supply outputs for the majority of the time. They are briefly switched to the input mode each time an input reading is taken. The connectors and circuits are designed so that it does not matter which way around the connectors on sensors are fitted to the ports of the RCX unit. There are four possible orientations, and a sensor will work properly whichever of the four orientations is used.

One role of the diode array is to make sure that the supply always connects to the main circuit with the correct polarity. Due to the brief gaps in the supply it is necessary to include a smoothing capacitor in the supply circuit. The exact supply voltage depends on the state of the batteries in the RCX unit and the level of loading, but it is usually around seven volts. Another function of the diode array is to ensure that the output of the buffer amplifier drives the input port correctly, whatever the orientation of the sensor's connector.

Circuit Operation

The full circuit diagram for the ultrasonic sensor appears in Figure 2. The diode array is comprised of D1 to D6, and a standard bridge rectifier circuit is formed by D1 to D4. This provides the seven-volt supply in conjunction with smoothing capacitor C3. A bridge rectifier provides full-wave rectification, so it does not matter which way around the circuit is connected to the RCX unit. The circuit will always be provided with a supply of the correct polarity.

An internal pull-up resistor in the RCX unit normally takes the input terminal to its full-scale potential. D5 and D6 enable the output of IC1a to pull the input terminal of the RCX port down towards the 0-volt supply rail. Again, it does not matter which way round the unit is connected to the RCX unit. The output of IC1a will connect to the 'hot' input terminal of the port via one or other of the two diodes. During the periods when the input is providing the supply, one or other of the diodes will block the supply so that only an insignificant current flows through the two diodes. The output of IC1a is connected across the supply during these periods, but R1 prevents an excessive output current from flowing into IC1a's output stage.

IC1a is the buffer amplifier and it is a conventional voltage follower stage. IC1b is the d.c. amplifier. It operates in the non-inverting mode and its closed loop voltage gain is set at 3.7 times by feedback resistors R2 and R3. Note that the LM358N used in the IC1 position is a device that is intended for use in d.c. circuits that lack a negative supply. Most other dual operational amplifiers are not able to provide the very low output voltages called for here and will not work in this circuit. Few operational amplifiers work properly at the low supply voltage used here, and the use of substitutes is not

recommended. TR1 amplifies the output from Mic1, which is the receiving transducer. TR1 is used as a simple common emitter amplifier that provides over 40dB of voltage gain. C2 couples its output to a simple half-wave rectifier circuit using D7 and D8. C1 and R4 form the smoothing circuit.

The transmitter circuit is just a basic 555 timer (IC2) used in the standard oscillator configuration. The maximum supply current that the RCX unit can provide from each input port is quite limited, and it is advisable to use a low power version of the 555 for IC2. There is otherwise a risk that loading on the supply will be so great that an inadequate supply potential will be obtained. VR1 is the frequency control, and it is normally adjusted to produce optimum performance from the circuit. However, it can be deliberately offset from the optimum frequency if reduced sensitivity is needed.

Construction

The stripboard layout and wiring for the ultrasonic sensor are shown in Figure 3, and the cuts in the copper strips on the underside of the board shown separately in Figure 4. The board has 39 holes by 12 copper strips, and it is designed to fit into the guide slots of a suitable plastic case (Maplin Catalogue code YU52G). This is a neat solution to fitting the board in the case, but it does result in the use of a case that is somewhat chunkier than is really necessary. It is possible to use the board in practically any small plastic case that can accommodate the 100-millimetre length of the board. At least three extra strips are then needed at the top of the board to provide space for a couple of mounting holes so that the board can be bolted in place, and a board of 39 holes by at least 15 copper strips is then needed. Metric M2.5 mounting bolts are suitable.

Building the board is largely straightforward, but there are a few points that merit some amplification. The first point is that it is not a good idea for complete beginners to undertake a project of this type. The RCX unit is designed to take a certain amount of mistreatment, and there is probably little real risk of damaging the unit if a mistake is made in the construction of the sensor. However, bear in mind that the manufacturer's guarantee will not cover any damage caused in this way, and spare RCX units are expensive.

Neither of the integrated circuits are particularly vulnerable to damage from static charges, but it is still a good idea to fit both components on the board via a holder. The OA91 diodes used for D7 and D8 are germanium devices, which give better performance in this application than silicon diodes due to their lower forward voltage drop. The circuit will still work very well if OA91 diodes prove difficult to obtain and silicon diodes (1N4148, etc.) are used instead. Germanium diodes are more vulnerable to heat damage than the silicon variety, so take due care when fitting D7 and D8 to the board. It is not essential to use a heat-shunt when making the soldered connections, but each joint should be completed reasonably quickly. After soldering the first lead in place allow the component to cool of slightly before connecting the other lead.

Make sure that all the diodes are connected with the correct polarity, but be particularly careful with D1 to D6. Internal circuits limit the maximum output current from the RCX unit, and mistakes are unlikely to cause any damage. However, it is best not to put this type of thing to 'the acid test'.

There is little space available for capacitors C1 and C3, which must be miniature radial (printed circuit mounting) types if they are to fit properly into this layout. C2 must be a type that has leads rather than pins in order to fit this layout, and a Mylar type is probably the best choice. A polyester or polycarbonate component having 7.5 millimetre (0.3-inch) is suitable for C4.

If the board is being used with the case mentioned previously and its built-in guide-rails, it will probably have to be filed down so that it tapers slightly towards the front. This is necessary to match the slight tapering of the case, which is noticeably narrower towards the front.

In most respects the general layout of the unit is not critical, but one exception is that the ultrasonic transducers (Mic1 and LS1) must be mounted a reasonable distance apart. Practical tests suggest that as little as 25-millimetres separating the transducers will give a suitable low level of direct coupling, but it is advisable to err on the side of caution and use a gap of 40 millimetres or more. The transducers are normally sold as a pair, and they are not usually identical. The transmitting unit is usually marked with a type number starting with a 'T', such as 'T16-40'. Similarly, the receiving transducer is normally labelled with a type number that starts with a letter 'R', such as 'R16-40'. The retailer's catalogue or other literature on the transducers should make it clear which device is which.

Ultrasonic transducers do not normally have any form of built-in mounting bracket. The easiest way of mounting them on the case is to drill holes about 2.5-millimetres in diameter to accommodate the two pins at the rear of each transducer, and then glue them in place. A good quality gap-filling adhesive is needed. An epoxy type is suitable, but a hot glue gun provides the quickest and easiest means of fixing them in place. Some ultrasonic transducers have one of the pins connected to the metal case. Where appropriate, this pin should be the one that connects to the 0-volt supply rail.

Making Connections

A small hole is drilled in one side of the case to take the lead for the Lego connector. This connector is based on a 2 by 2 Lego brick, and is obviously a non-standard type. There are various options available when connecting do-it-yourself projects to an RCX unit. It is possible to make your own connectors using standard 2 by 2 Lego bricks as the basis. A tour of web sites devoted to

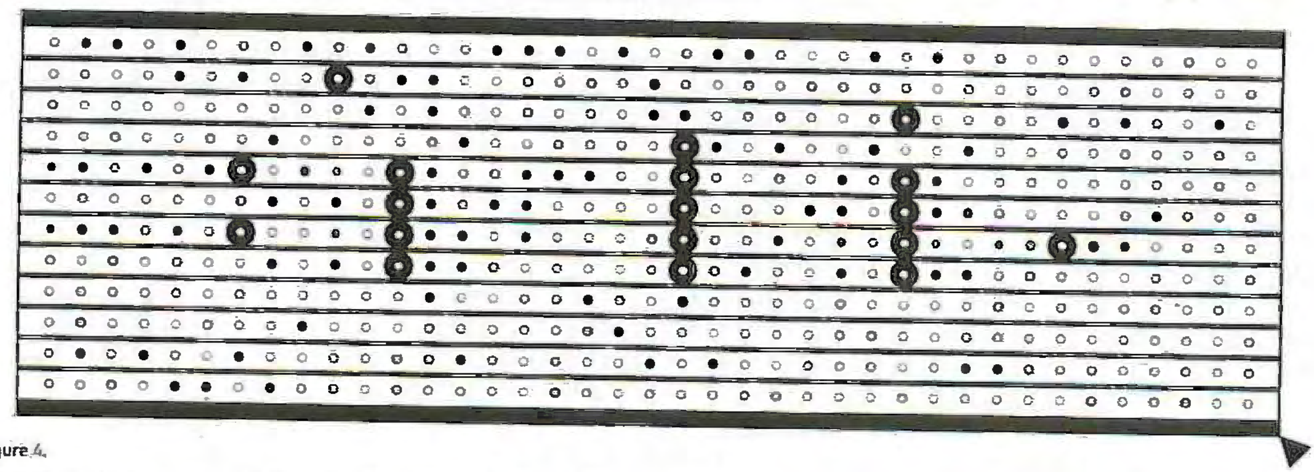
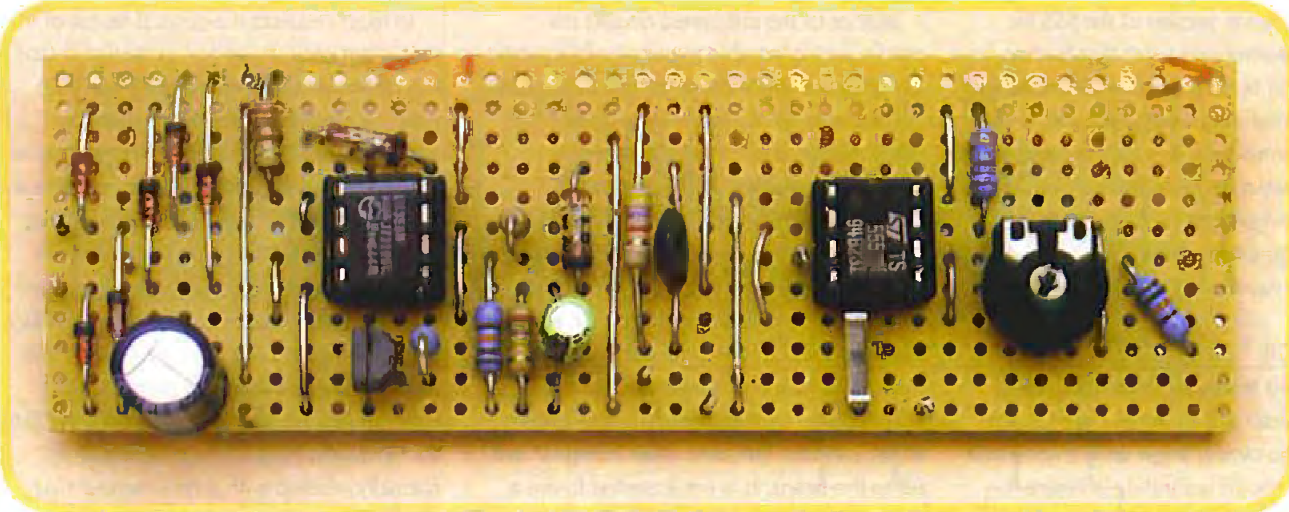


Figure 4.



Lego MindStorms should soon produce some details of home-made connectors. An easier method is to either buy some Lego connecting cables or sacrifice one of the long leads supplied in the MindStorms kit. The long leads are little used in practice, so many Lego project builders prefer to use one of these rather than buy an extra cable from a specialist Lego supplier. Cutting a connector plus about 200 millimetres of lead from each end of the cable provides two leads that can be used to connect your own devices to the RCX unit.

There is actually a third option available in the form of the connector plates that are available from specialist Lego suppliers. One of these can be mounted on the project and wired to the input of the circuit. The connector plate then connects to the RCX unit using a standard Lego lead, much like connecting the RCX unit to a touch sensor.

Some means of mounting the sensor on Lego robots is required, and gluing a Lego brick to the underside of the case is the best method. Due to the relatively large size of the sensor a fairly large brick such as a 6 by 2 or 8 by 2 type is best. Either the top of the brick must be filed flat or it must be glued in place using a good gap-filling adhesive.

Testing and Use

After a final check of the wiring the sensor is ready for testing. Start with VR1 at a roughly middle setting. The easiest way to test and set-up the sensor is to connect it to an input of the unit that is set for operation with an active sensor such as the Lego light type. The sensor will not work at all with an input set for use with a passive sensor such as a touch type, since it will not receive a significant supply voltage from the input port. Connect the sensor to the appropriate input port and switch on the RCX unit. Keep pressing the View button on the RCX unit until the arrow cursor indicates that the correct input port is being monitored by the display.

The sensor should work to some degree, with a high reading being obtained with the transducers aimed into a large empty space, and a much lower reading being produced if you place your hand in front of and close to the transducers. The maximum reading will probably be less than 100, and will usually be between about 80 and 90. The minimum reading will probably be zero, or something close to zero. If the sensor is clearly non-operational, switch off immediately and recheck the wiring, etc. If it works to some degree, the next step is to adjust VR1 for optimum performance.

Start by aiming the sensor at a wall, and then move the unit just far enough away from the wall to produce a high reading on the display. Then adjust VR1 for the lowest possible reading. It is likely that the reading will go right down to zero. If so, move the sensor further away from the wall to restore a higher reading and then readjust VR1 for the lowest possible reading. It might be necessary to repeat this process a few times in order to produce the largest possible operating range.

The maximum range of the unit will probably be around two metres, which is too great for use in small rooms. The sensitivity of the circuit is easily reduced, and it is just a matter of adjusting VR1 away from the optimum setting. Suppose that a maximum operating range of about 0.5 metres is required. Position the sensor about 0.5 metres away from a wall and aim it at the wall. Then adjust VR1 for a low reading, but a reading greater than zero. The sensor should then operate with approximately the required range.

The ultrasonic sensor is handled in the software in exactly the same way as any other active type. In RCX code it can be used as if it was a light sensor. When using the sensor in this way bear in mind that a high reading is obtained when empty space is detected, and a low reading is produced when an object is detected. Things operate the other way round if Raw mode is used when reading the sensor.

Parts List

Resistors

R1	2k7
R2	27k
R3,R7	10k (2 off)
R4	270k
R5	1M5
R6	4k7
R8	2k2

All 0.25 watt 5% carbon film

Potentiometer

VR1	10k min horizontal preset

Capacitors

C1	1u 63V radial electrolytic
C2	10n Mylar
C3	470u 10V radial electrolytic
C4	1n polyester

Semiconductors

IC1	LM358N
IC2	TS555CN
D1 to D6	1N4148 (6 off)
D7,D8	OA91 (2 off)
TR1	BC549

Miscellaneous

LS1	40kHz ultrasonic transducer (see text)
Mic1	40kHz ultrasonic transducer (see text)

Small plastic box.
0.1-inch stripboard having 39 holes x 12 strips.
8-pin DIL holder (2 off).
Lego connector and lead (see text).
Lego brick, wire, solder, etc.