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Module: Characterizing Active sensors - Ultrasonic

Module Introduction

An easy to use robust device that can be used to sense the proximity of objects within a field-of-view is the Ultrasonic Sensor. It is a Sonar system that transmits a series of ultrasonic pulses, receives the signal scattered back to the device and generates a pulse whose width is related to the distance to the closest object in the field-of-view. The most cogent manual can be found at https://www.mpja.com/download/hc-sr04_ultrasonic_module_user_guidejohn.pdf.

Figure 1: image of the front of the Ultrasonic Sensor

As you can see from the figure there are 2 devices one sends an ultrasonic signal and the other receives it. The operation and design are proprietary so even the chips on the back have no designations to indicate their purpose. But the basic operation is summarized in the figure below that was found in the document mentioned above.

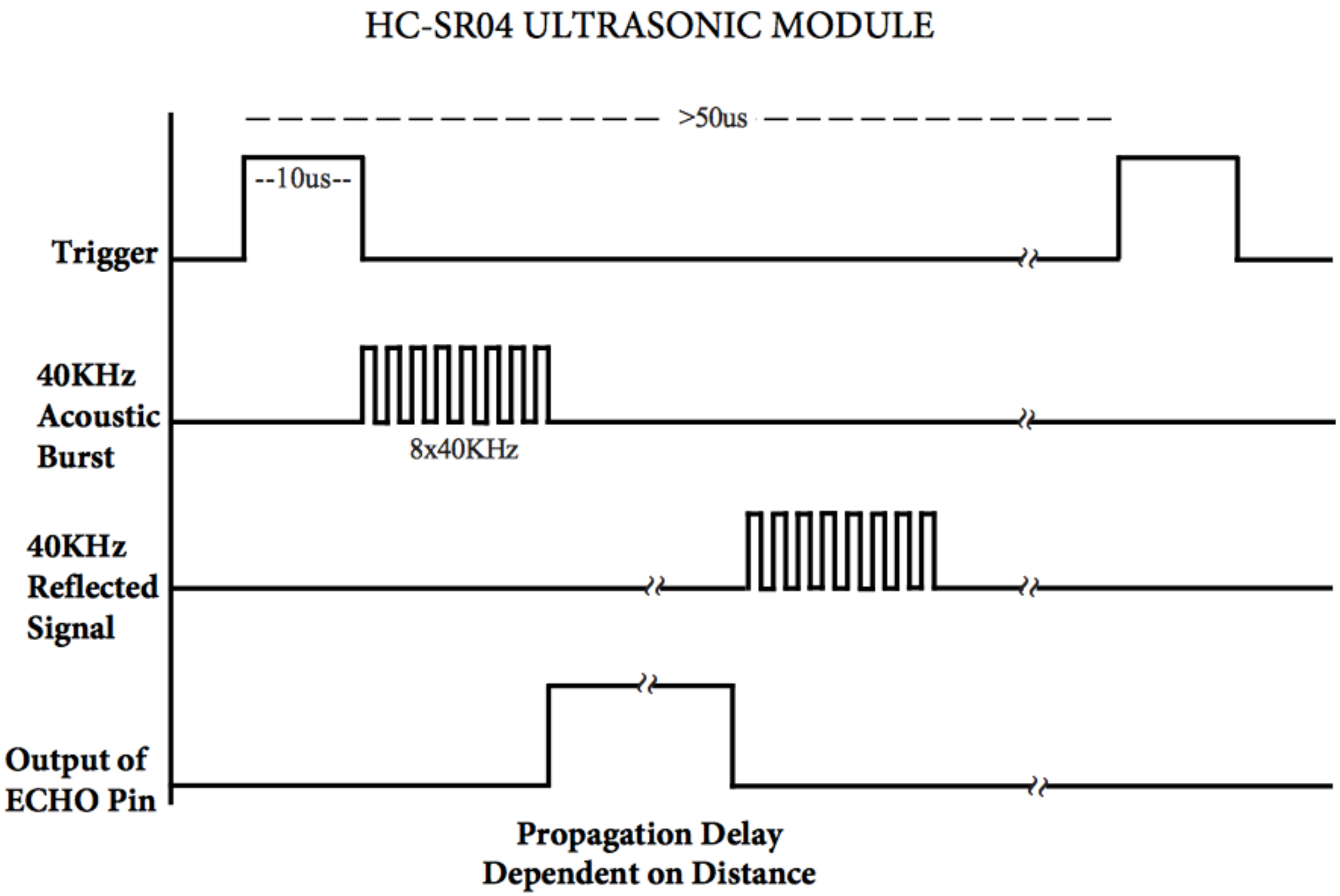

Figure 2: Timing of signals – the Trigger is provided by the user to initiate the detection sequence that generates the ECHO signal.

Besides the two pins labeled V_{cc} and GND that indicate how to power the device there are two other pins ***Trig*** and ***Echo***. To indicate to the device when to probe the field-of-view with an ultrasonic signal a TRIGGER signal is used. The trigger signal is generated by the user and is simply a square pulse that is initially 0V transitioning to V_{cc} for a proscribed length of time – this

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signal must be provided by your circuit. This trigger signal causes the device to transmit an ultrasonic signal that consists of eight short bursts of a signal at 40KHz (the figure only shows the amplitude of the 40kHz signal so the pulses are square without the sinusoidal variation) – ultrasonic frequencies are those that exceed 20KHz. A timer is started on-board the device that starts right when the last of the eight bursts is finished initiating a voltage of V_{cc} on the ECHO pin that transitions back to 0V when the first signal consisting of 8 ultrasonic bursts returns. This means that the width of the pulse available at the ECHO pin is related to the distance to the *nearest object* in the field-of-view.

This device is very easy to use but there are some considerations that depend on your applications. Some things to consider are: i) the characteristics of the trigger signal, ii) the size of the field-of-view, iii) the resolution i. e. how small an object can be detected, and iii) longest and shortest range detectable.

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Pertinent Information

The data given describing the technical specifications of the sensor system are summarized in the list below. The information given actually answers all of the questions posed. The manufacturer claims that the maximum range is 4m, the minimum is 2cm, and the trigger signal must be at least 10µs wide. How often should the trigger signal be sent? If the trigger signal is longer than 10µs will the device work as expected? What are other questions that might be asked when characterizing this device?

HC-SR04 Specifications

- Working Voltage: DC 5V
- Working Current: 15mA
- Working Frequency: 40Hz
- Max Range: 4m
- Min Range: 2cm
- Measuring Angle: 15 degree
- Trigger Input Signal: 10µS TTL pulse
- Echo Output Signal Input TTL lever signal and the range in proportion
- Dimension 45 * 20 * 15mm

Generating the Trigger Signal and Interpreting the Echo Signal

These devices are most commonly used in a mode that continuously probes the environment by sending out bursts of ultrasonic pulses at intervals determined by the designer – you. The receiver on the device indicates the closest object via the echo signal. To do this so that the range of the closest object is unambiguous you must wait once the trigger pulse is applied to the device so that the signal scattered from the farthest object detectable would have enough time to get back to the receiver.

In this portion of the module you will play with the relationship between the trigger pulse and the

To characterize the device you need to come up with a setup. The simplest method is to insert the sensor into a protoboard.

- ✓ The four pins are well labeled on the board. Connect the power and ground pins to 5V as supplied by the power supply or the Arduino/RedBoard 5V Pin.

As Einstein pointed out distance and time are integrally related in the sense that when we are measuring distance we always have to send out a signal of some kind – in our case sound - and wait (time word) for its return. But the speed of sound at 343.2 m/s weighs in at only .000001% the speed of light so the distance can be computed from the time it takes the transmitted signal to reach the receiver using the non-relativistic formula speed*time=distance.

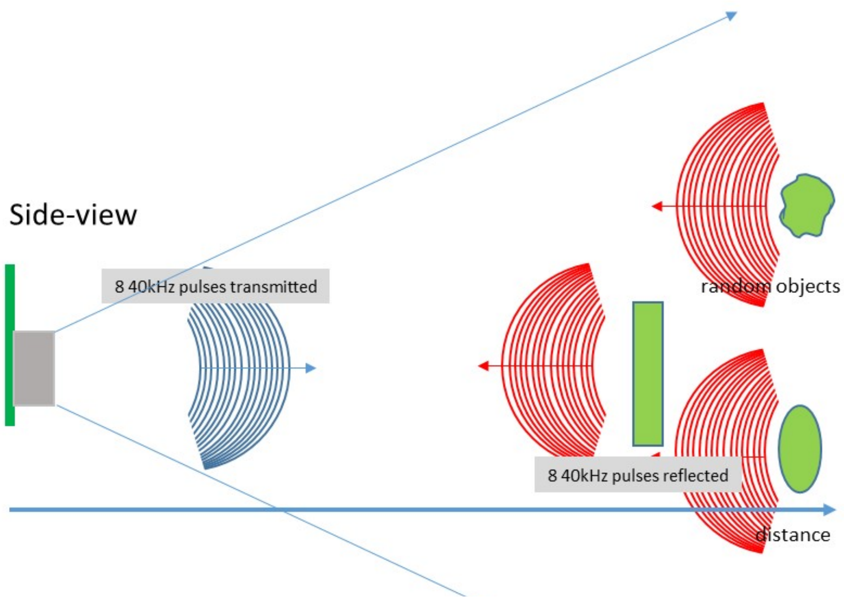

Figure 2: Timing of signals – the Trigger is provided by the user to initiate the detection sequence that generates the ECHO signal.

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Question 1: How long does it take sound to travel the alleged farthest distance of 4m and return to the receiver that is located on this device at about the same location as the transmitter.

- ✓ Set the signal generator to output a square wave with a frequency of 50Hz that varies from 0V to V_{cc}=5V as indicated on the datasheet with a 50% duty cycle.
- ✓ Monitor the ***trig*** pin on channel 1 of the oscilloscope.
- ✓ Monitor the ***echo*** pin on channel 2 of the oscilloscope.

Play with the sensor by moving your hand around to see how the echo signal changes as your hand gets closer and farther from the sensor.

Question 2: How does the echo signal change as your hand is moved closer and farther from the device?

Question 3: Qualitatively - Is the change linear with distance?

Many devices that have timing considerations rely on square pulses to *trigger* some circuit inside – in this case the transmission and reception of an ultrasonic signal. If only the edge is really needed to start – then we could generate it without having to worry about precise timing.

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- ✓ Set up you sensor to be looking at a stationary object – your choice.

Question 4: At 50 Hz and 50% duty cycle what is the width of the pulse? – it should be way longer than the specified 10µs. Vary this width and see if the returned echo changes in both the position in time of the rising edge with respect to the rising edge of the trigger and the more important parameter the width of the echo.

Determining Maximum and Minimum Range

This might be a little tricky to do since the maximum is claimed to be 4m which is about 12 ft.

- ✓ Keeping the trigger pulse the same and keeping the protoboard in a fixed location set up on books or the wooden blocks so that it is not sitting directly on the table move your hand closer and farther from the device.

Question 5: Plot the trigger and echo signals from the scope at the point where the width of the echo signal stops varying as you move your hand or a flat surface closer to the device. Measure this distance and write it on the plot. You may have to zoom in on the oscilloscope to detect small changes.

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Question 6: Plot the trigger and echo signals from the scope at the point where the width of the echo signal stops varying as you move your hand or a flat surface farther away from the device. Measure this distance and write it on your plot. If the distance is larger than 1m you can stop and label the largest distance you tried.

Question 7: Based on your estimates of the realistic maximum and minimum range would a trigger signal with a frequency of 100Hz be adequate to resolve most of the objects near the sensor – remember this is the frequency of the signal that you generated using the oscillator circuit as part of lab 8.

Determining Field-of-View

To use these sensors effectively you need to know where they "see" the best. Most of the other sensors in your kits and the common ones used for applications like line-following are used at such a close distance from sensor to object sensed that the field-of-view is not an issue. If you want to use these sensors to help navigate your vehicle this may be an issue because the car chassis and mounting surfaces are close to the floor so the floor might be inside the field-of-view. The sensor will not respond to objects that are too high so the vehicle may run into certain obstacles that do not trigger an echo but are still in the way.

- ✓ With the same setup hold the protoboard as far away from things as possible.

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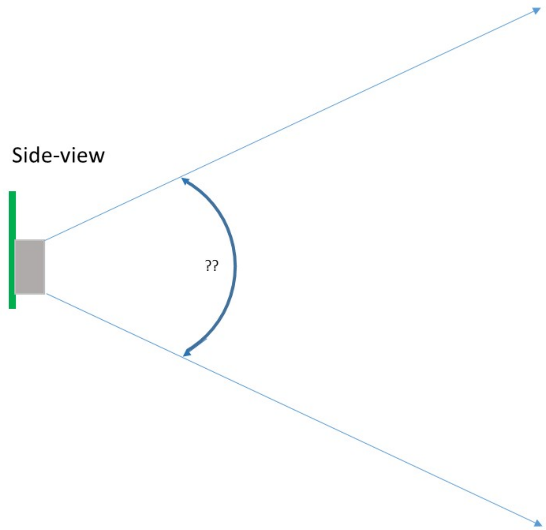
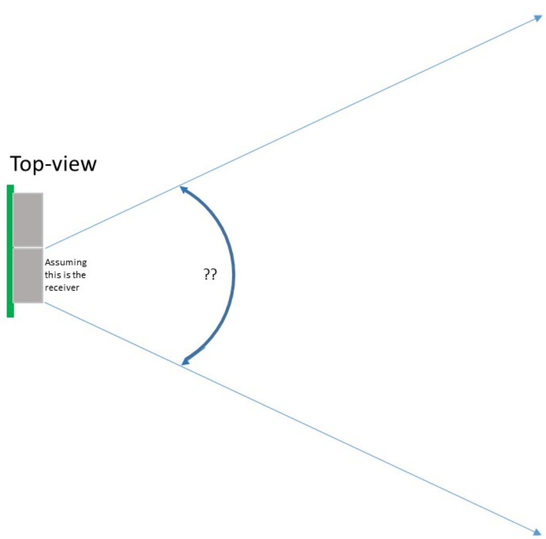
Question 8: This part is a little qualitative but by holding your hand or other flat object at a fixed distance (attaching a string from the sensor to your hand maybe) and moving it along the arc up and down estimate the angular vertical extent.



Question 9: Again, try to estimate the horizontal extent of the field-of-view.



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Hum – there are two transducers on the board that look like eyes. One is the transmitter and one is the receiver… Probe the sensors using the oscilloscope to see the actual voltage signal used to transmit and the voltage signal generated on receive. To probe these signals you will have to just hold the oscilloscope probes and if you want to see both someone else needs to hold the probes connected to the other sensor.

Question 10: (OPTIONAL) Which one is the receiver? How did you determine the answer?