

Executive Summary

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Executive Summary

Preface

Any robot that is to make decisions without human help, needs information on which to make those decisions. This information is supplied by sensors, eg. a decision as to whether a robot is turning a wheel at the correct speed requires a sensor to gauge the speed of that wheel.

The exact number and type of sensors, depends upon the robot's reason for existence; robots in pre-planned, non-changing environments, eg car welding robots, require few sensors, whereas robots designed to be mobile and carry out procedures in unplanned environments, require as many sensors as possible, to enable the robot can operate without hinderance from its environment.

This project was to design and build one such sensor; A proximity detection and range-finding system to give the mobile robot the ability to `see' obstacles etc. by using the echoes from acoustic waves, so preventative measures can be taken to avoid these obstacles. This system of obstacle-sensing, is not new; bats have used it for the last 350-400,000 years, with great success.

Objectives

The objectives of this project were;

- 1). To design and build a proximity detection and range-finding system for the mobile robots (Mini-Mobots), using ultrasonic transducers.
- 2). To design the system such that it could also be used as a simple inter-mobot communications system.

Introduction to the Mini-Mobot

The Mini-Mobot is a small, simple mobile robot, designed for use in Multi-robot interaction and robot colony experiments. It is a 10cm diameter, cylindrical robot, that moves on 2 wheels, with a support, front and back, to stop the mobot toppling over as shown in 1.

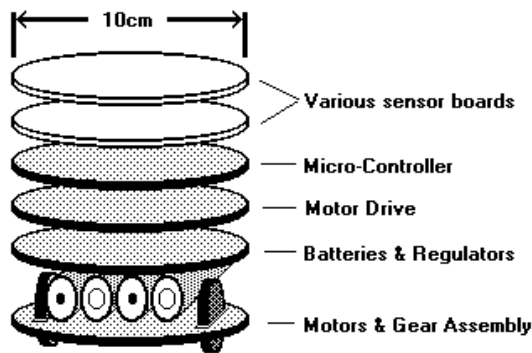


Figure 1 Physical layout of a Mini-Mobot

The basic mobot has 4 main parts, all connected by a 'spine' of connectors. The main board is the Micro-Controller board which runs the mobot. The microcontroller has both a program memory and a data memory, as well as serial communications system, and runs programs on the EPROM onboard. On top of the microcontroller board sits various sensor boards as required

Overview of Ultrasonics

Ultrasonic waves are sounds that have a pitch above the upper limit of human hearing and are normally frequencies of above 20kHz. They have similar properties to sound waves, these characteristics being:-

1. Wavelength and Velocity of Propagation - The velocity of wave propagation for all sound waves through air is about 344m/s (at 20°C). At these relatively slow velocities, wavelengths are short, ranging from a few centimetres for low frequencies, down to a few hundred micrometres for high frequencies. The actual velocity of propagation is affected mainly by temperature, increasing by about 3.5% between 0°C and 20°C.

2. Reflection - As with all waves, sounds waves produce reflections (echoes) when they hit an object. These echoes are the basis of all acoustic range-finding and proximity detection. Metals, wood, concrete, glass, rubber, and paper are good reflectors, so they can be easily detected, whereas Cloth, cotton, wool etc. absorb ultrasonic radiation and therefore are difficult to detect.

3. Attenuation - The Amplitude of the ultrasonic signal decreases with distance, therefore an echo from a far object will be of very low amplitude.

Producing Ultrasonic Signals

Ultrasonic signals are produced using the piezoelectric principle; when an electric signal is added to a vibrator, constructed of a sheet of piezo-electric ceramics bonded to a metal sheet, an ultrasonic signal is radiated by flexure vibration. The vibrator is bonded to a conical resonator, in order, in the transmitter, to efficiently radiate the ultrasonic waves generated, and in the receiver, to concentrate the ultrasonic waves at the centre of the vibrator.

Due to the reversible nature of piezoelectrics and acoustic waves, just one transducer is necessary, used alternatively as emitter or receiver. The main problem with this is that it results in a 'blind-zone', while the vibrations, due to sending, decay to a level at which return signals can cause the transducer to vibrate. If 2 separate transducers are used, this problem should not occur, unless signals feed directly from the sender to the receiver. Spacing the transducers a distance apart, and padding each with a layer of elastic material, such as rubber, sponge etc, reduces this problem.

The 'vision' angle for the transducer pair is 100° and areas outside of this can be thought of as 'blind' areas, so to cover 360°, ie all-round vision, at least 4 pairs are required, mounted on a board on the mini-mobot.

The Theory of Operation

As noted on the last page, all ultrasonic range-finding is based upon an ultrasonic signal echoing when it hits an object. This echo returns to the transducers after a time proportional to the distance travelled by the wave. This theory is used by all 3 main methods of range-finding:-

1). Pulse-echo - In this case, the transmitter is pulsed, and the time interval between the transmitted pulse and the received echo is proportional to the distance; for example if an object was 1 metre away, the distance covered would 1 metre to the object, then 1 metre back to the receiver. Therefore the time interval would be;

$$t = \frac{1+1}{344} \approx 5 \bullet 8mS \quad \text{at velocity of sound} = 344m/s$$

If no echo is received within the allotted time, the assumption is made that there is no object within range. The main advantage of this system is simplicity; no calibrated frequencies, or phase detectors are required. The disadvantage is that the system is at best, only accurate to within about 2cm. A limitation on the system is that there must be only one pulse in the air at any one time, as the echoes give no indication of which 'parent' pulse they came from.

2). Frequency-Modulated, Continuous wave - A sophisticated system that can measure both distance and relative velocity. The Transmitter emits a continuous signal that 'sweeps' the full ultrasonic frequency range (say from 20kHz to 200kHz), while monitoring the return echoes. From the frequency difference of the return signal to that being sent, the time since it was transmitted, and thus the distance to the object can be estimated. Also, with faster moving targets, the Doppler effect becomes useful, giving relative velocity. This method requires transducers with a good frequency response over the whole frequency range and precise oscillators, but give sub-millimetre accuracy.

3). Continuous wave, phase difference When an echo returns, it has a phase difference to the signal being transmitted, indicating the distance, minus a whole number of wavelengths, the wave has travelled (ie if it travelled three and a half wavelengths, the phase difference would be equal to half a wavelength). If a beat frequency is used, the effective wavelength would be long, and the phase difference would indicate the distance. This method needs two precision oscillators, but gives pin-point (micro-metre) accuracy.

Methods 2 and 3 were thought to be overkill, both too complex, and being continuous wave, total confusion would occur in multi-mobot situations where 2 or more robots are range-finding at the same frequencies. This leaves only pulse-echo as a possibility. It has the advantage of simplicity and although pulse collisions could still occur if 2 or more mobots are within range of each-other, this will only occur if a pulse from one is received by another, in its pulse-echo time-window, a chance of about 1 in 500 for 2 mobot together. It should be noted though, that pulse collisions **will** occur once in a while, and even just environmental noise could cause problems, but steps can be taken to reduce the probability of this occurring, especially in software if the hardware is as basic and software-controlled as possible. Methods include;

1). Checking the 'air' first - ie if another mobot is pulsing or sending communications data, indicated by a high ultrasonic sound level, wait until finished.

2). Pulse-echoing twice (ie double checking), with a random time period in-between, and then checking that an echo on one trace, is also present in a similar position on the other.

3). Whisper - if the mobot is just wanting to range-find at close range (0-20cm), the pulse length can be reduced in length and volume, ie the system would be looking for an echo from a whisper). Only objects close to the mobot would echo and these echoes would be of small amplitude; any large amplitude received pulses, would have to be from an other mobot pulsing at normal intensity.

4). Check the echoes amplitude - any echo from a far-off object should be much attenuated; if not, it must be a pulse from another mobot.

The hardware was designed with these methods in mind, and allows the software to control the output pulse, and to get a trace of the return echoes; both position and amplitude.

Basic layout of the system

The requirement was for a pulse-echo system, where the pulse length is software controlled, and the return is processed by the software. Although 4 transducers are required for all-round 'vision', only one pair can be operating at once (to stop interference with each-other). Thus there is no need to duplicate all the circuitry 4 times; most of the circuit can be common to all 4 transducer pairs.

The transmission side of the circuit drives a transducer using the pulse given to it by the microcontroller. The transmitted pulse then echoes from any objects present, and are picked up by the receiver transducer. All received signals are of tiny amplitude (< 2 mV for a 'loud' echo), so the signal requires to be amplified (by 2000), before anything else is possible. It is then peak-detected to remove the 40kHz modulation, then converted to a digital level, which is sent to the microcontroller. It processes it, and converts the echoes to distances, using its onboard clock to time the delay from pulse to echo.

The communication side of the design was just to modulate any serial output signal sent by the microcontroller. This modulated signal out drives all 4 transmitters, and all 4 receivers are always listening for any received signals, which is demodulated and given to the microcontroller to decode. The final block diagram as shown in 2.

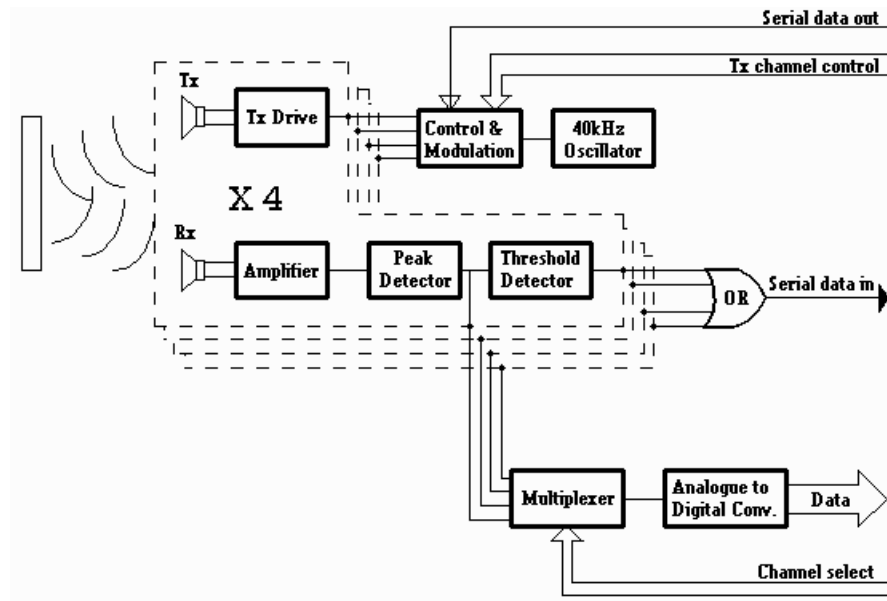


Figure 2 - Block diagram of the system

Design of the actual circuit

The general criteria for the actual circuit was to build the circuit as small as possible, using as few components, and as little power (<50mA) as possible, and used 74HC series chips throughout. The designed circuit was tested at prototype stage, when it was built on strip-board, and alterations made, before it was laid out on the final Printed Circuit Board. This was then built and tested. Due to lack of time, and the Mini-Mobots having not been fully built yet, the tests were accomplished on the final design on it own, without the rest of the Mini-mobot

Tests on the Communications

The communications side of the system was only tested at a basic level, to check that what was sent by one Mobot, could be picked up by another. For this, two systems were set up 40cm apart; one transmitting ...010101010101... continuously at 220 Bits/sec. The second system was placed about 40cm away in a very cluttered environment of test equipment and other objects, to produce as many echoes as possible and simulate a worst case situation. This system was then monitored, to see that it was receiving the transmission correctly. It was, although due to the echoes, the modulated level encroaches on to the unmodulated level's bit, but not by enough to

confuse the microcontroller which takes the best of 3 readings of each bit received, to guard against noise. At baud rates above 220, the received signal becomes more and more uneven, before becoming totally destroyed by echoes at about 500 Baud.

The main conclusion of the communications test was that comm's at up to 220 bit per second worked, without error, in a cluttered environment, and in an uncluttered environment, 300 Baud could be used.

Tests on the range-finder

For all of the range-finding tests, the system was set up on the edge of a desk, with one pair of transducers pointing outwards. The sender transducer was then pulsed for 165 μ S and the echo signal, from the system, stored using a digital storage oscilloscope.

1). With no objects present - for an empty area the trace, see 3, showed the one unexpected result to come out of the testing of the final PCB design. The large amplitude return signal at the start of the trace, 800 μ S long is due to the transmitter 'deafening' the receiver, both by air and by vibrations through the PCB, to which both are attached. On the prototype, the two transducers were mounted on two separate boards about 2cm apart and padded with foam, and hence gave very little signal by direct feed. On the final design they are 9mm apart, causing the receiver to resonate badly. At first it was thought that this would preclude any detection in the first 15cm, but later tests showed the system could proximity detect objects closer, but without any exact value of distance, ie all it know was that the object was closer than 15cm.

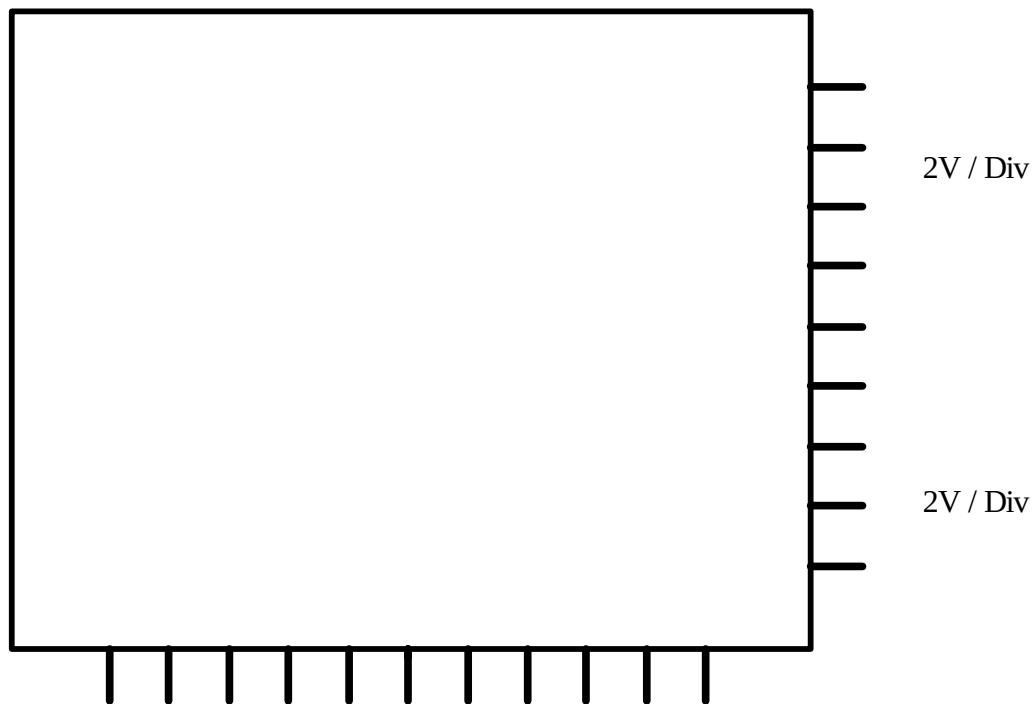


Figure 3
 Top trace; modulated output pulse
 Bottom trace; the received signal for no object echoes

2). With objects present - when an object is within range, the return echo is very sharp, as shown in 4 for a object 80 cm away from the system, and after converting to digital data by the 6 bit Analog to Digital converter, the data values only started increasing, when an echo front was present; electrical noise and voltage ripple did not show up on the digitized data at all. therefore even if the software was just checking for a data value that was larger than the last, even just by 1, it would detect object succesfully without a high error rate for all but long range (ie greater than 150 cm).

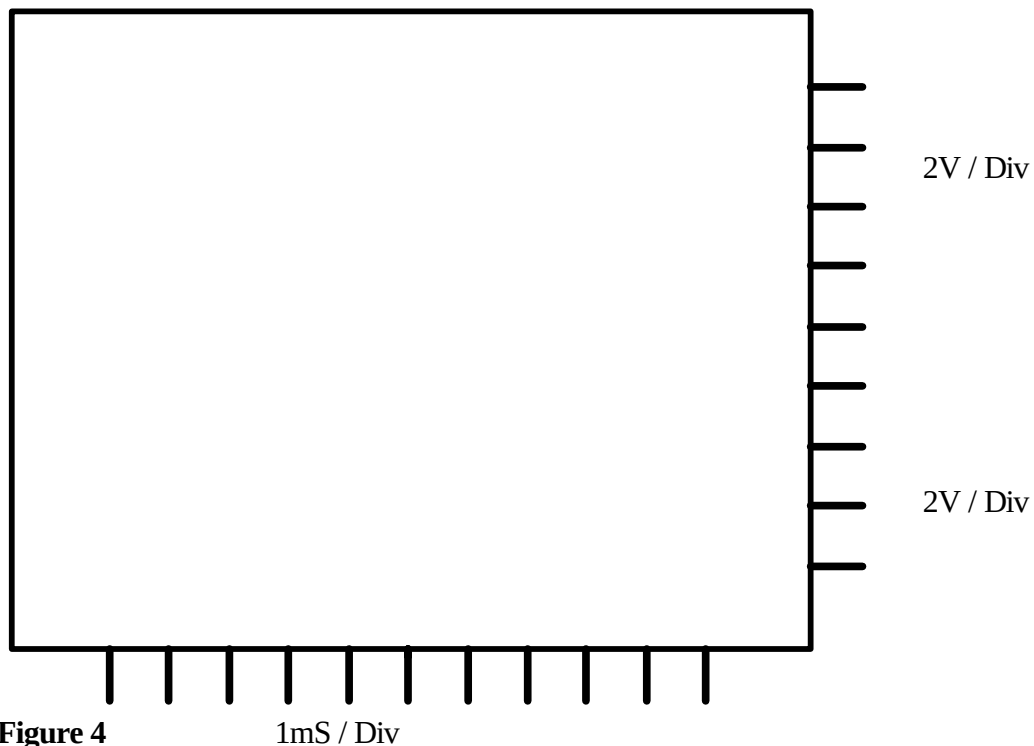


Figure 4
Top trace; echo signal after amplification
Bottom trace; signal after peak-detector

Conclusion

The system worked as planned, with the possible exception of at close range. Areas needing further work are; writing software to be used on the system, improving the communications baud rate, and solving the 'deafening' problem suffered by the receiver transducers just after pulse transmission, possibly by redesigning the PCB they are mounted on.