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An Ultrasonic/Optical Pulse Sensor for Precise Distance Measurements

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Abstract **- The combined ultrasonic transit time and optical pulse method described here is an improvement over the standard ultrasonic echo by providing a lower signal loss and more precise location of sensor reference points, specifically the transmitting and receiving transducers.**

The ultrasonic transit time sensor described here uses only a one-way ultrasonic pulse. The transit time, typically 0.5 to 50 ms, is proportional to the distance between the ultrasonic transmitter and receiver transducers. There are three advantages: (1) the ultrasonic signal loss is much less, (2) the location of the transducers is well defined, and (3) the phase and pulse shapes are controlled and reproducible. An optical pulse is used to synchronize the transmitter and receiver. In this version the optical pulse is sent from the ultrasonic receiver unit, initiated by its microcontroller, to the ultrasonic transmitter unit.

I. INTRODUCTION

The determination of the three dimensional position of objects within a room or other area using conventional magnetic, optical or vision sensors is often imprecise, thus limiting their usefulness. Ultrasonic echo methods can be accurate under controlled conditions, but the signal loss with varying atmospheric conditions [1, 2], the shape of the object, surface profile, distance between the objects, propagation angles reduce sensor accuracy significantly [3].

For example, with collision avoidance sensors, an ultrasonic pulse train, typically 5-20 cycles at 40 kHz, is transmitted through the air to the mobile object where it is reflected. A receiver located near the transmitter detects limits the range to about 1 to 5 meters with an uncertainty of 1-5 cm for head-on echoes. The weak echo and records the echo (sound round trip) time. Wind and other atmospheric disturbances usually

We describe here a sensor which combines ultrasonic transit time and an optical pulse method. It is an improvement over the standard ultrasonic echo method by providing a much lower signal loss and more control of the ultrasonic transmitter and receiver signal shapes.

II. SYSTEM DESCRIPTION

The block diagram (Fig. 1) illustrates the infrared and ultrasonic signal flow. The microcomputers control the system operation. Initially an optical pulse is transmitted from the ultrasonic receiver unit. Upon receiving the optical pulse at the other unit, an ultrasonic pulse is transmitted back to the receiver unit.

The time of flight for the optical signal is negligible so the microcontroller (at the receiver unit) starts its timer as the optical signal is sent. Hence the timer value when the ultrasonic pulse is detected at the receiver unit is the transit time for the ultrasonic signal between the transducers. From this time of flight and the sound velocity, the distance between the transducers can be calculated

The applications of this approach are limited to situations where the transducers and associated electronics can be mounted on both ends of the distance to be determined. Thus proximity detection, which uses echo, is eliminated

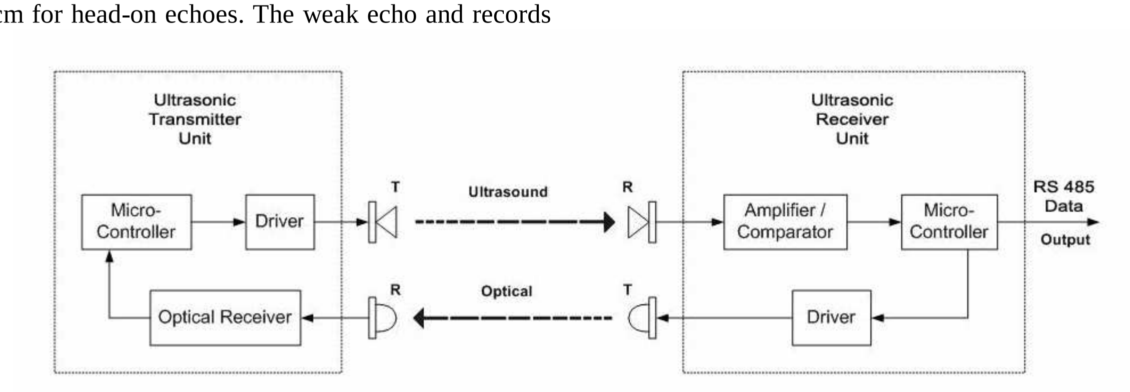

Fig. 1. System Block Diagram

III. OPTICAL SIGNAL DESCRIPTION

The IR (870 nm) transmitter is an LED which is turned on (pulsed) by the transistor connected to microcomputer (Fig 2). This pulse (0.5 ms) acts as a start signal. A lens built into the LED provides a 10 degree beam width.

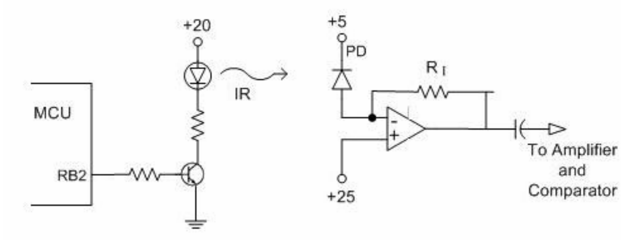

Fig. 2. Basic IR Pulse Transmitter and receiver

The photodiode at the ultrasonic transmitter (IR receiver) has an IR filter so that stray room illumination is rejected. Its current output is converted to a voltage pulse by the input amplifier (Fig. 2). Subsequent amplifier stages increase the signal strength and act as a high-pass filter to further reduce low frequency noise. At the comparator output the optical signal has the shape shown in Fig 3 (the transmitted signal has a similar shape). The rising edge of the pulse is the synchronization signal.

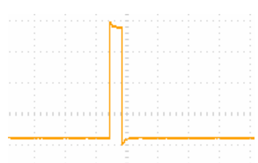

Fig. 3. Received Optical Pulse

IV. TRANSMITTED ULTRASONIC SIGNAL

Conventional ceramic piezoelectric transducers are used for both the transmitter and receiver. Tuned transducers ring (40 kHz) when excited by a single square wave pulse (impulse). The electronic driver is shown in Fig. 4. The transmit wave train due to a single pulse or impulse has a long exponential decay (Fig. 5b, also see Fig 8b) because of low damping. While the transmit rise time due to an impulse is distinct; the received signal response is not. This causes excessive uncertainty to the arrival time of the received

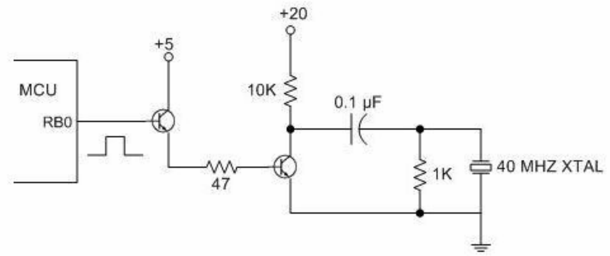

Fig 4. Ultrasonic Transmitter Transducer Driver

signal. To shape the transmitted signal, a second pulse is sent to the transmitter transducer with a delay of 1.5 cycles (see Fig. 5a). Since it is 180 degrees out of phase, the second pulse cancels subsequent ringing so that the propagating ultrasonic pulse is just 1.5 cycles of a sine wave at 40 kHz (Fig. 5c).

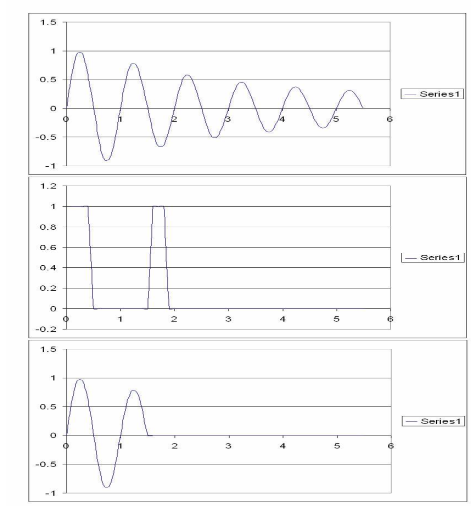

Fig. 5. Transmitter Waveforms: a. Driver, b. Single Pulse Response, and c. Dual Pulse Response.

The transmitter transducer voltage waveform is shown in Fig 6. The large negative signal is due to the capacitive coupled pulse produced by the brief turn-on of the driver transistor (Fig. 4).

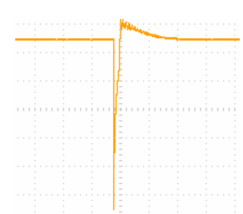

Fig. 6. Measured Transmitter Transducer Waveform

V. ULTRASONIC RECEIVER

A high gain (x100) receiver (Fig. 7) amplifies the signal from the receiver transducer and the output (Fig. 8a) is connected to a comparator which, when the signal exceeds a threshold level, detects the received pulse.

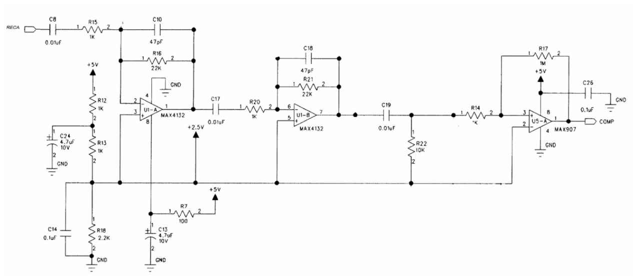

Fig. 7. Ultrasonic Signal Amplifier

The resulting received signal then has a distinctly shaped rise, even with a transducer which rings (Fig. 8a), and therefore the arrival time is more reproducible. This allows the arrival time to be measured to a fraction of the period and thus the distance to a fraction of a wavelength. The advantage is a faster rise-time and more precise waveform, while the disadvantage is a much lower transmit amplitude than with the conventional method of exciting with a wave train of multiple cycles. This disadvantage is overcome here by using one-way ultrasonic signal transmission instead of an echo.

If the transmit waveform is not properly shaped by the second pulse, the transducer will ring excessively.

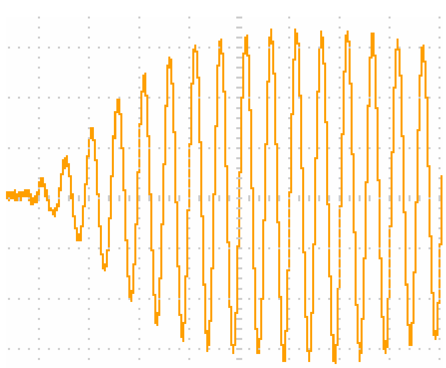

Fig. 8. Received Ultrasonic Signal

VI. MICROCOMPUTER SIGNAL PROCESSING

The attached microcontroller (Fig. 9) detects the comparator rise, records the arrival time and measures the time between the optical pulse transmission and the ultrasonic pulse reception. Knowing the velocity of sound, it then converts this information to the distance (x) between the ultrasonic transducers.

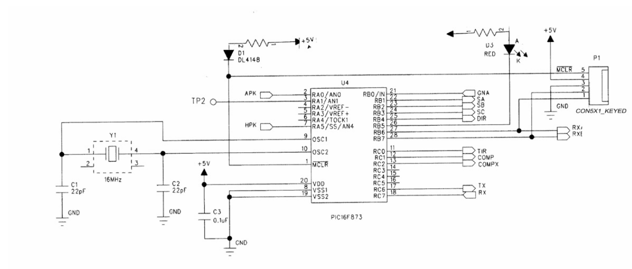

Fig. 9 Microcontroller Circuit

The data is transferred to an external computer using a RS485 serial data bus.

VII. PERFORMANCE TEST

The measured distance measured by the ultrasonic sensor was compared with the actual distance between the transmitter and receiver transducers. This is shown in Fig. 10.

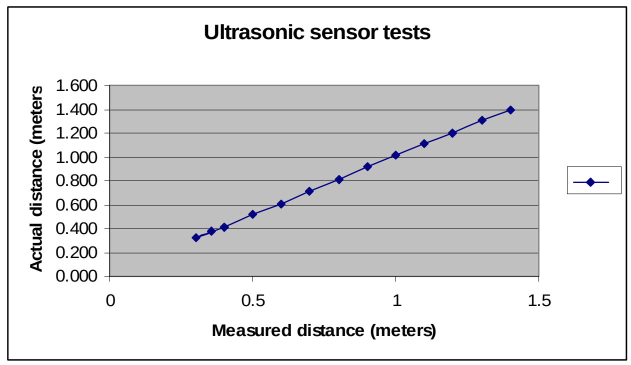

Fig. 10 Sensed vs. Actual Distance

VIII. APPLICATION

The specific application for this sensor is an x-ray dose monitor. The purpose is to monitor, and thus minimize, x-ray dose during surgery [4]. The transmitter unit is placed on the x-ray source arm, which is moving, and the receiver unit is stationed, on the patient table, which is also mobile. This allows the source to table distance to be determined. A separate sensor measures the table to floor distance so that, by triangulation, the positions of the x-ray source and patent with respect to a fixed point on the floor are known.

REFERENCES

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[3] Giovanni Bucci, Carmine Landi, "Numerical Method for Transit time measurement in Ultrasonic Sensor Applications IEEE Transactions on Instrumentation and Measurement", Vol. 46 No.6, Dec 1997..

[4] X-ray Dose Tracing Website: www.dosetracking.org