Ultrasonic Localization System for Wireless Sensor Networks

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ABSTRACT: This paper introduces a WSN (Wireless Sensor Networks) localization method based on ultrasonic (US) TOF (time of flight) measurements. The participants send out U.S. signals while a central location unit calculates the TDoA (Time-Difference-of-Arrival) between four U.S. sensors for the AoA (angle-of-arrival) calculus. Additionally the sensor node radio frequency (RF) transceiver makes distance measurements using TDoA (US vs. RF). This greatly increases the precision of localization because the approximate distance from triangulation suffers disproportionately from even small errors of angle. The number of outliers and variations of the measured distances and angles are reduced by several filter stages including Kalman-filtering. Such computed polar coordinates (angle / distance) are converted into a Cartesian shape and transmitted to a base station connected to a PC. The mean error and standard deviation of angle and distance measurements (1.40 ° ± 0.50 ° / 1.00 km ± 0.20 km) result in a slight mean position error of 5.21 cm and a standard deviation of 0.70 cm, respectively.

KEYWORDS: Wireless Sensor Networks, Localization; Ultrasonic, Time-of-Flight Distance, Angle Measurement.

INTRODUCTION

The ultrasonic sensor is an electronic device that determines a target object's distance by transmitting ultrasonic sound waves, and transforms the sound reflected into an electrical signal. Ultrasonic waves propagate quicker than visible sound (i.e., sound that can be heard by humans). Ultrasonic sensors have two main components: the transmitter (which uses piezoelectric crystals to emit the signal) and the receiver (which follows the signal after it travels to and from the target). To determine the distance between the sensor and the target, the sensor calculates the time it takes to its interaction with the receiver between the emission of the sound by the transmitter. For this equation the formula is D = 1⁄2 T x C (where D is the distance, T is the time and C is the sound speed ~ 343 meters / second) [1].

Sound wave is a transmitted vibration through a medium such as air, water, and metals. Ultrasonic wave is described as "high frequency, inaudible sound for humans" whose frequency typically exceeds 20 kHz. Shock wave that isn't meant to be felt these days is often called ultrasonic wave. There are types of ultrasonic waves, longitudinal waves, transverse waves and surface waves etc. Two types of elastic waves occur simultaneously in a solid. One is an elastic wave with a displacement in the same direction of the wave's propagation direction called longitudinal wave or density wave and another is an elastic wave with a displacement to the vertical direction of the wave's propagation direction called traverse wave or shear wave [2].

Ultrasound is acoustic frequencies between 16 kHz and 1 GHz; it is call as "ultrasonics" in industrial environments. To clarify: people can hear frequencies between 16 Hz and 20 kHz; i.e., the lower industrial ultrasonic frequencies are audible, particularly if secondary frequencies are produced. And what's more, when using the weld tool ultrasonics is palpable. The frequency range for ultrasonic welding lies between 20 kHz and 70 kHz [3].

Ultrasonic sensors are primarily used as proximity sensors. They can be used in self-parking and anti-collision protection systems for passenger vehicles. Ultrasonic sensors are also used in applications for robotic detection of obstacles, as well as in production technology. Compared to infrared (IR) sensors in proximity sensing applications, ultrasonic sensors are not as prone to smoke, gas and other airborne particles interference (though variables such as heat still affect the physical components). Ultrasonic sensors are also used as level sensors in closed containers to track, control, and regulate liquid levels (such as vats in chemical factories). Ultrasonic technology has, most importantly, helped the medical industry to generate photographs of internal organs, classify tumors and ensure baby health in the womb [4].

Ultrasonic distance sensors are designed to measure non-contact distance and these types consist of transmitter and receiver or transceiver capable of transmitting and receiving ultrasonic sound. The main concept is to calculate time to travel from sensor to sensed source of ultrasonic sound wave. The ultrasonic transmitter delivers a sound frequency through the air above 18 kHz at an approximate speed of 350 meters per second (at 20 °C) and the receiver absorbs the signal from the object reflected. The distance between the transmitter and the target can be determined by easy calculation, considering the time taken to travel from the transmitter by the ultrasonic wave and received back (reflected) by the receiver.

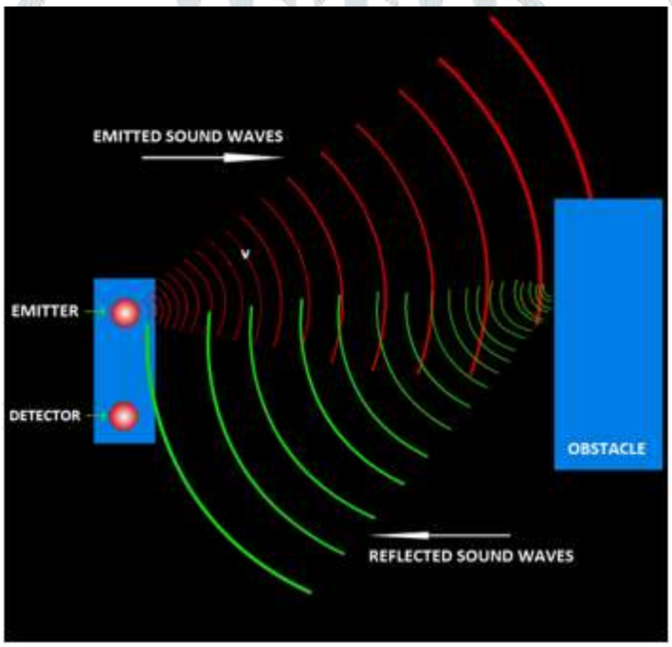

Fig. 1 Shows Us How Ultrasonic Sensor Works And How Emition And Detection Of Reflected Wave Occurs.

The sound waves are mirrored by almost all objects, and ultrasonic sensors are a good alternative for many tasks. Such sensors differ from their photoelectric counterparts by excellence in the identification and measurement of films, transparent objects and liquids. Goal color or regular changes in color often have no effect on ultrasonic sensors.

Ultrasonic sensors also perform well in dusty, polluted conditions, because of their use of sound waves. However, against large backgrounds or targets such as foam tossing, they do not perform well with small targets which are excellent for absorbing sound waves. A standard ultrasonic sensor consists of a generator clock (signal) and a controller to excite the transducer, then a processor and an amplifier to manage the return signal. In addition to the theory of flight time, physical concepts based on the Doppler Effect and sound wave attenuation are also used. Application is commonly used as navigation sensor for mobile robots to avoid obstacles.

LITERATURE REVIEW

This presentation deals with checking the accuracy of the ultrasonic sensor for measuring distance in the current environment. SFR08 style equipped with an I2C communication interface which allows addressing was chosen as a measuring sensor. This reality makes the array of sensors easy to build. PC-based control system and even visualization framework. NI USB 8451 used as contact card. Verification measurements aimed to determine the actual accuracy of the sensor particularly when measuring longer distances. The calculated data was not used in temperature compensation when determining the sensor's accuracy [5]. This research aimed to develop an optimal transducer for efficiently generating the two simultaneous longitudinal modes. It first developed a suitable mathematical model by combining the continuum bar model and countermeasure with the condition of compatibility between a piezoelectric actuator and a linear horn. This paper then used a finite-element approach to determine the optimum length of the aluminum horn and piezoelectric actuator. The proposed sensor had a half-power bandwidth of less than ±1,3° at 44,8 kHz, which was far higher than the existing traditional ultrasonic range sensors [6]. In this paper, addressed the efficiency comparison of ultrasonic and infrared measurement techniques through obstacles of various material types. The layout of the vehicle integrated with the sensors, traveling at constant speed through various types of obstacles through capture the distance parameter. The correlation study of the measured distance with actual distance performed is based on the data acquired from the sensors. This analysis would be useful in selecting the right sensor-ultrasonic sensor / infrared sensor or a combination of both sensors when designing the algorithm to resolve obstacle detection issues [7].

LOCALIZATION MEASUREMENT SYSTEM

This research focuses on a ToF [8] technique as opposed to a previous multilateration implementation focused on distance measurements with RSSI (Received Signal Strength Indicator) that led to huge distance and therefore localization errors. Our first method was a triangulation strategy, but since the angle error is up to 250° (see Fig. 2 and Tab. 1), it is inefficient to estimate the intersected angle size. An additional radio frequency (RF) pulse is sent to allow a TDoA distance measurement to improve the accuracy [9].

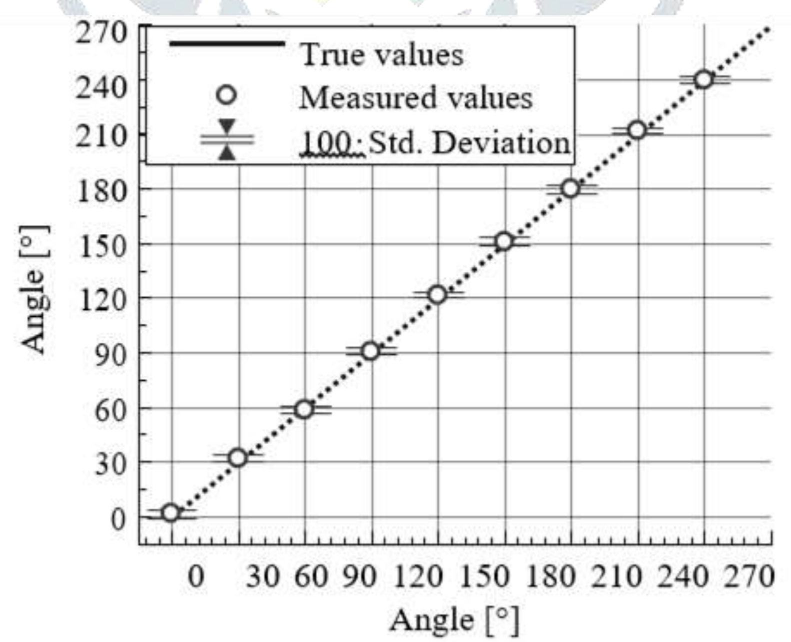

Fig.2 Results of Angle-of-Angle Measurements.

True values	Measured values	
	Mean	Std. Deviation
0	2.50	3.03×10-2
30	45.51	2.55×10-2
60	75.75	2.44×10-2
90	110.77	2.50×10-2
120	160.09	2.02×10-2
150	200.21	3.25×10-2
180	230.70	2.97×10-2
210	280.46	2.33×10-2
240	300.40	2.59×10-2

Tab.1 True Value, Mean, and Standard Deviation of Angle-Of-Angle Measurement.

The sensor node sends a US / RF pulse to the FPGA-based timestamp measurement receiver. To minimize the number of outliers and anomalies, the attached sensor node processes the data through Kalman-filtering. The determined polar coordinates (angle / distance) are converted into Cartesian form and transmitted to a base station that is connected to a PC. The angle measurement at each receiver is based on the specific ToA,

$$\alpha_t = 90° - acos\left[v_{RF}(\Delta t_4 - \Delta t_1)/\left(\sqrt{2}d_s\right)\right].$$

Because the propagation speed of US signals is insignificantly small relative to RF signals, the distance dt can be approximated.

$$d_t \approx \Delta t_5 \cdot v_{RF}.$$

The wireless sensor node microcontroller (MSP430) has a sample frequency of approximately 32 kHz. For a side length d(s) = 8 cm from the US receiver board, the angular resolution would be 5.4 ° resulting in a localization error of up to 14 cm @ 150 cm. We used a Xilinx Spartan-3E FPGA board as a digital sampling system with a sample frequency of 50 MHz which causes an error below 1 cm under the same circumstances [10].

A global control sequencer, a serial data communication module (UART), an internal timer, and a finite state machine (FSM) are typically used to implement the hardware. It also comprises input / output (IO) ports, connecting the system to the US receiver board as well as to the wireless sensor node (Telos Rev. B). The global sequencer controls the exchange of data by taking into account several predefined operating constraints. The FSM manages the entire transmission process which includes the order for data transmission or UART configuration.

RESULT

The final experiment to check our method includes eight measurements of indoor location for each position on the outline of a rectangle of 3 m x 3 m including 1000 samples.

$$\text{RMS error} = \sqrt{(x_t - \bar{x})^2 + (y_t - \bar{y})^2}.$$

Considering all measurements, the mean is 4.21 cm and has a standard deviation of just 0.57 cm The findings are shown in Tab for all single positions. 2.

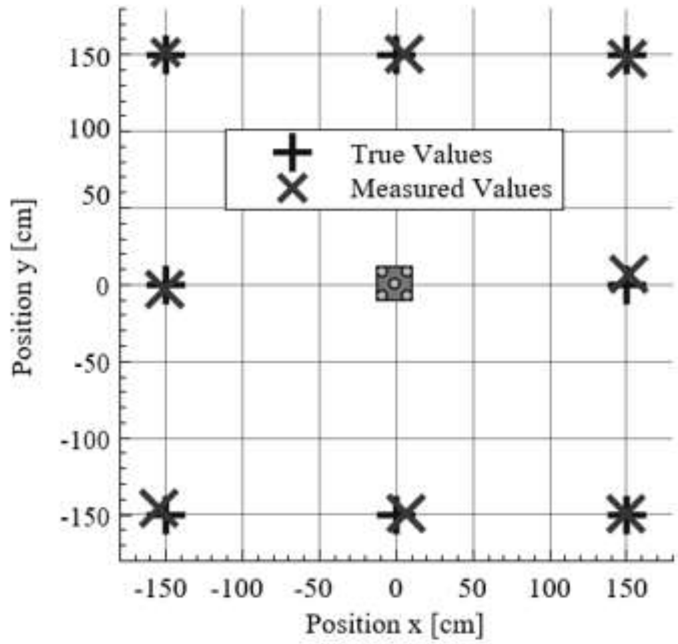

Fig. 3: Visualization of Localization-Measurement.

Position		Mean Error		RMS-Error	
x	*y*	*xt-x*	yt-y	Mean	Std-Dev
-150	150	-0.20	1.70	1.79	0.60
0	150	5.59	0.70	5.40	0.20
150	150	0.37	-2.50	2.60	0.29
-150	0	-0.80	-2.80	3.00	0.30
150	0	1.40	7.30	6.30	3.00
-150	-150	-4.50	4.58	6.59	0.20
0	-150	6.69	1.10	6.59	0.19
150	-150	-0.60	0.80	1.10	0.30

Tab. 2 Result of Localization Measuremnent.

CONCLUSION

Ultrasonic sensors have a broad variety of applications such as distance measurement, obstacle avoidance and anti-collision detection, robot navigation, measurement in car parking assistance systems, air flow velocity measurement-anemometer, medical ultrasonography, non-destructive monitoring, piezoelectric transducer, level measurement, forklift pallet detection, vehicle detection in barrier device. Ultrasonic sensors are non-intrusive in that they do not need physical contact with their target, and can detect those transparent or shiny targets that are otherwise blurred by other sensors based on vision. In comparison, their measurements are very sensitive to temperature and target angle. Temperature and humidity affect sound velocity in air. Range finders that therefore need to be recalibrated to perform accurate measurements in a new environment. Variations in temperature and air currents can establish invisible boundaries that mimic ultrasonic waves so caution must be taken to prevent these. The target surface must be perpendicular to the transmitter for the transmitted wave to echo back to the receiver. Therefore, round objects are most easily detected because they often display a certain perpendicular profile. When targeting a flat surface, care must be taken to ensure that its sensor angle does not exceed a given range.

A measuring system was provided using angle and distance measurements via US for accurate and reliable localization in WSN. It's much more descriptive and reliable compared with RSSI using US and ToF. But there are also some drawbacks: the US uses more energy, has a smaller range and the speed of sound depends on the temperature and humidity in the environment. Nevertheless, such positive outcomes can only be obtained by ToF techniques. And as the US is much slower than RF, the FPGA time-measurement specifications are less stringent.

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