A Software Based Method for Improving Accuracy of Ultrasonic Range Finder Module

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***Abstract*—This paper presents the statistics-based algorithm in order to increase the accuracy of the obstacle range measurement. This research is implemented on the concept of filtering approach and is only applied for the low-cost ultrasonic range sensor. The experiments are conducted on the HC-SR04 module and results are compared to the traditional methods. The results are shown that the accuracy of this proposed algorithm is similar to the traditional method, the measurement speed it significantly faster.**

Keywords—ultrasonic; noise filter; signal processing

I. Introduction

The ultrasonic range finder module is an electronic sensor module used to determine the distance from the sensor to the object. This sensor works by transmitting the ultrasonic wave, a high frequency audio wave, from the transmitter, and used the audio receiver to pick up the reflected audio wave. The time duration between audio is send and audio is received is then converted to the distance, the details are shown in Fig. 1.

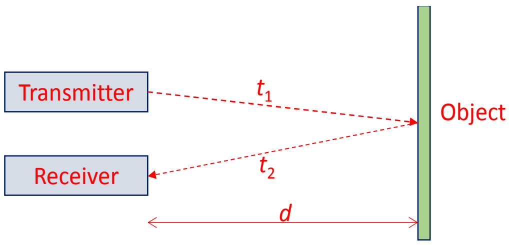

Fig. 1. The basic concept of ultrasonic range finder

The distance is calculated using (eq1), where *d* is the distance in centimeter, *t* is the time duration from the transmitter to the receiver (t_1+t_2) in microsecond, c is the speed of sound in the air which is varied based on air temperature and humidity. However the changing in humidity does not cause the significant influence in the distance measurement because of the uncertainty principle[1]. The most parameter that can influence the speed of sound is the temperature, the widely equation which is used to estimate the speed of sound is (eq2), where ϑ is the air temperature in degree Celsius. The (eq3) can be used to estimate the aped of sound with more precision [1]

$$d = \frac{tc}{2\times 10000} \tag{1}$$

$$c = (333.1 + 0.606\vartheta) \tag{2}$$

$$c = 20.05\sqrt{\vartheta + 273.15} \tag{3}$$

The ultrasonic range finder is used in a variety of applications such as obstacle detection, reverse car parking sensors, parking space sensor and flash-flood detection[2]. This module also used for object recognition and indoor positioning[3]. The ultrasonic range finder module which is commonly used in the developer community is the “HC-SR04” module[4], the device is shown in Fig. 2. This low-cost module using 40kHz audio wave to detect the range, it can measure the distance from 2cm to 400cm, and the field of view is 15 degrees.

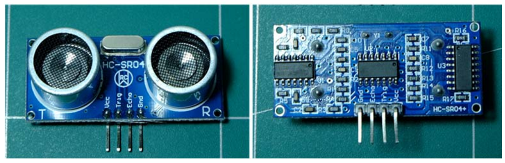

Fig. 2. HC-SR04 Ultrasonic range finder Module

The advantages of using ultrasonic to measure distance are fast, non-invasive and low hardware cost. However the accuracy of measure distance based on ultrasonic also has some drawback. The ultrasonic range sensor determines the distance based on time-to –flight of an ultrasonic sound wave, but the speed of sound is not constant. There are many parameters that can influence the speed of sound such as air composition, humidity and temperature[5]. There is some approach to overcome these problems based on hardware implementation.

The noise detection is introduced by[1] for ping signal adaptation and build in temperature compensation circuit. The hardware zero-crossing detection is replaced by digital signal processing to gain more accuracy[6]. The Kalman filter also introduced to eliminate noise signal[7], or event using the coded signal to eliminate noise from sensor crosstalk[8]. The Neural network is also introduced to detect the zero crossing signal[9]. These previous works are focused on hardware implementation, signal layer processing is required. The accuracy can be significantly improved, but it required hardware hacking and it is not simply to be done on the widely available cheap hardware.

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In this research, we focus on the low-cost ultrasonic range finder HC-SR04. The characteristic of this module is studied and the algorithm to improve the accuracy based on software implementation is proposed.

II. THE TESTBED DESCRIPTION

This section describes the hardware and software setup that used to collect the data used to evaluate the algorithm. In this research the hardware is implemented to simulate the range finder in real world situations. There are two parts are described in this section, the hardware that is used to collect dataset and the test scenario.

A. The hardware

The hardware used to collect the dataset is composed of four HC-SR04 modules, these devices are manufactured by the same company and purchase from the same retailer. DHT22 is used as the temperature sensor module to collect the air temperature data. The Arduino Pro Mini development board is used to control HC-SR04 module and DHT22 module, this development board is based on an ATmega328p running at 16MHz with an external X-TAL resonator.

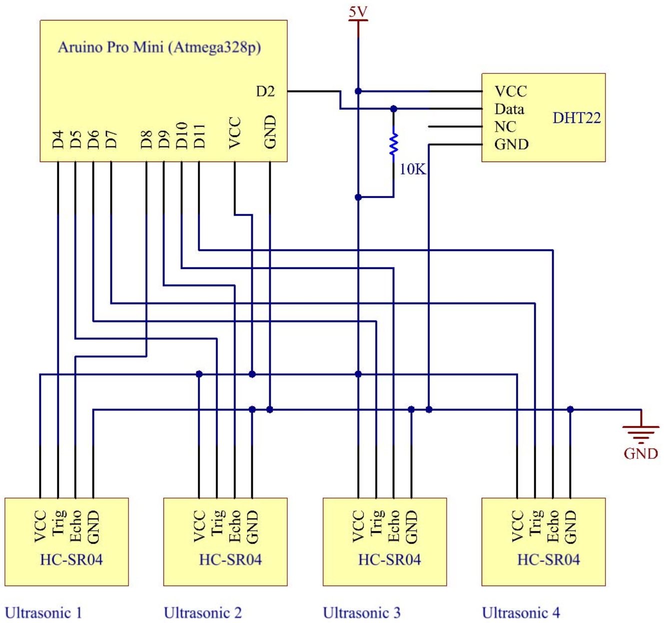

Fig. 3. The schematic of ultrasonic data acquisition hardware

The software is started by reading the temperature from DHT22 module, and reading the time duration from ultrasonic module from Ultrasonic 1 to Ultrasonic 4 respectively, and then the 2000 samples of each ultrasonic sensor are collected. The ultrasonic sensors do not operate at the same time, it has to wait until the echo is received or it will wait for 10 millisecond before it can start a new ping. This method guarantees that no cross talk from other sensors is happening[8]. The schematic of the hardware is shown in Fig. 3, and the actual hardware is shown in Fig. 4.

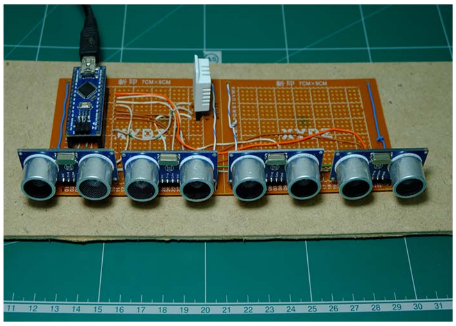

Fig. 4. The actual hardware used in this research

B. The test scenario

The test scenario is designed to simulate the operation of the car detection for parking space sensor. In this research, the ultrasonic sensor is placed on the table 147cm form the floor, the wooden flat board is used as an obstacle, the setup layout is shown in Fig. 5. The setup is done on the open space with an averaged ambient noise 56 dBA.

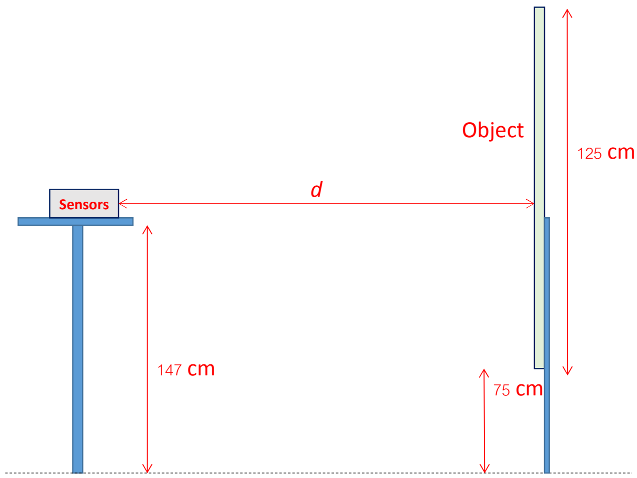

Fig. 5. The sensors setup

III. THE PROPOSED METHOD

By analyzing the raw data collected from the sensors, we found that there are some spike data occurred in the sensor output. These spikes are more likely to happen when the sensors are far away from the object. In this research, we proposed filter algorithm based on the Mode of Mean. The proposed algorithm is shown in Algorithm 1, where S is the array of raw sensor data, n is the window size, θ is the tolerance value, r is define the confident value, d is the filtered result.

The algorithm starts by getting input data from the sensor for n samples. Then all samples are averaged and stored in the memory. If the data stored in the memory are similar to the new incoming data, then this data is considered "Valid". If incoming data is not similar to the previously stored in the memory, then it is considered "Invalid", and the process will be started over again until it gets the valid data.

Algorithm 1

Input: S, n, θ, r	
Output: d	
Step 1:	While $j < r$
Step 2:	$d \leftarrow \frac{1}{n}\sum_{i=j}^{j+n} S_i$
Step 3:	If $\lvert d - d' \rvert < \theta$ then
Step 4:	$j \leftarrow j + 1$
Step 5:	Else
Step 6:	$j \leftarrow 1$
Step 7:	End if
Step 8:	$d' \leftarrow d$
Step 9:	$j \leftarrow j + n$
Step 10:	End while
Step 11:	Return d

IV. THE EXPIROMENTS AND RESULTS

In this paper, the data from proposed algorithm is compared with three traditional methods for reading ultrasonic range sensor with and without the temperature compensation.

Method 1, one sample data is used to measure the distance (eq4), where S_0 is a sample raw data from the sensor, c is the speed of sound and d is the distance. The error is measure using (eq5) where k is the ground-truth.

$$d = \frac{S_0 \times c}{2 \times 10000} \tag{4}$$

$$Error = \lvert k - d \rvert \tag{5}$$

Method 2, this method is identical to the first method, but it is repeated for all samples (eq6). The error from each sample is then average to measure the overall performance (eq7).

$$D = \frac{S \times c}{2 \times 10000} \tag{6}$$

$$Error = mean(\lvert K - D \rvert) \tag{7}$$

Method 3, data are processed using a mean-filter, all samples are averaged to get a single value (eq8). The error is measured as same as the first method (eq5).

$$d = \frac{mean(S) \times c}{2 \times 10000} \tag{8}$$

Method 4, this method used each single sample from all sensors. These samples are averaged to get a single value and then used to calculate the distance (eq9), where $S1_0$ .. $S4_0$ are the one sample from sensor 1 to sensor 4

$$d = \frac{1}{4}(S1_0 + S2_0 + S3_0 + S4_0) \times \frac{c}{2 \times 10000} \tag{9}$$

Method 5, this is the proposed method. The raw sensor data are processed using Algorithm 1, where P is Algorithm 1.

$$d = P(S, n, \theta, r) \times \frac{c}{2 \times 10000} \tag{10}$$

All evaluation methods are done in two modes, no temperature compensation and use temperature data from sensor to compensate the difference in speed of sound. In the case of no temperature compensation, the sensor does not have a build-in thermometer, in these experiments we fixed $\vartheta = 29$, this value is the annual average temperature in Thailand[10]. In the case of temperature compensation, the both (eq2) and (eq3) were used for comparisons.

The data are collected at 28 points ranging from 7cm to 518cm. The ultrasonic time of flight is recorded in microsecond unit. If the echo do not receive in 100ms, then it is considered is ∞. The ∞ are filtered out, and the results are shown in TABLE I, it is shown that using only 1 sample (method 1) to determine the distance is not generating the accurate result. Large number of samples are required to get a more accurate result, method 2 and 3 are getting the accurate results but it used almost 2000 samples to achieve that. Method 4 is the best method in the term of accuracy, it is confirmed by paired t-test, it is only taking 1 sample to get the best result, however the four sensors are needed.

The accuracy of method 5 (proposed method) is similar to method 2 and 3, pair t-test is shown no significant difference. However the proposed method using a significantly lower number of samples, this will be result in the faster measurement with the same accuracy.

The differences in air temperature are the significant cause of the error, the results using (eq.2) or (eq.3) do not show the significant difference, but the (eq.3) is required more computation power due to the complex calculation.

TABLE I. NO ECHO RECEIVED EXCLUDED ERROR RESULTS (CM)

Method	Number of sample	Eq.2		Eq.3	
		Fixed	*Varies*	*Fixed*	*Varies*
1	1 ±0	8.659 ±37.454	8.195 ±37.291	8.782 ±37.476	8.235 ±37.333
2	1993.35 ±33.01	1.496 ±0.543	1.135 ±0.567	1.616 ±0.645	1.136 ±0.446
3	1993.35 ±33.01	1.467 ±0.539	0.939 ±0.515	1.597 ±0.645	0.993 ±0396
4	1 ±0	1.079 ±0.527	0.909 ±0.757	1.209 ±0.557	0.872 ±0.614
5	99.88 ±24.23	1.334 ±0.455	0.988 ±0.539	1.465 ±0.530	0.996 ±0.397

The TABLE II is showing the evaluation results where ∞ are not filtered out. This can be happened when the object does not reflect the ultrasonic wave such as sponge foam. In this case, the software is assigned “0” to all ping that do not echo back. The results of method 1 and 4 are identical because it only uses one sample, however method 2, 3 and 5 get lower accuracy by comparing with ∞ filtered.

TABLE II. NO ECHO RECEIVED INCLUDED ERROR RESULTS (CM)

Method	Number of sample	Eq.2		Eq.3	
		Fixed	*Varies*	*Fixed*	*Varies*
1	1 ±0	8.659 ±37.454	8.195 ±37.291	8.782 ±37.470	0.825 ±37.33
2	2000 ±0	1.969 ±2.435	1.607 ±2.639	2.088 ±2.517	1.609 ±2.497
3	2000 ±0	1.940 ±2.406	1.249 ±2.004	2.070 ±2.505	1.338 ±2.003
4	1 ±0	1.079 ±0.527	0.909 ±0.757	1.209 ±0.557	0.872 ±0.614
5	115.79 ±83.987	1.360 ±0.454	0.962 ±0.472	1.490 ±0.548	0.972 ±0.358

The accuracy of method 2 and 3 is deepened on the size the window. In these experiments the relationship between window size and measurement error also investigated, and the result is shown in Fig. 6. The trend is shown that the larger window size created more accurate measurement.

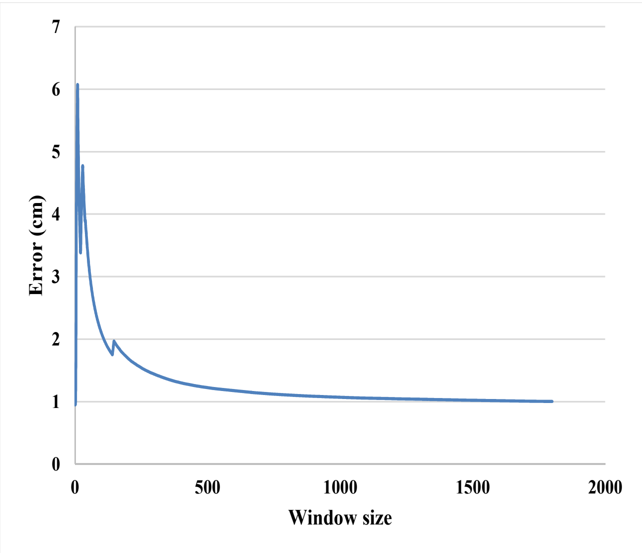

Fig. 6. The relationship of measurement error and window size of method.

V. CONCLUSION

In this research, the algorithm for ultrasonic range sensor accuracy improvement is proposed. The raw data from four ultrasonic sensors are prerecorded and then process later. The results are compared with four traditional methods. The results are concluded that, using one sample to determine the distance is not accurate and must be avoided, average multiple sample created better result, but it also increased the measurement time, the proposed algorithm created the same result with the average method, but required significantly less sample, this results in the faster measurement time, the best method is to use multiple sensors, but this method also increases the hardware cost and also increase the size of circuit footprint. The temperature compensation also required to produce the accurate measurement. However, using the estimation method or precise method to calculate the speed of sound do not affect the result in overall results.

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