Improving Efficiency of Ultrasonic Distance Sensors using Pulse Interval Modulation

Seungin Shin, Min-Hyun Kim, and Seibum B. Choi
Automotive Control Laboratory
Korea Advanced Institute of Science and Technology
Daejeon, Korea
minou93@kaist.ac.kr, minhyun@kaist.ac.kr, sbchoi@kaist.ac.kr

***Abstract*—In the robot research field, ultrasonic sensors have been highly employed for a long time. However, the sensors have used in the limited applications for near distance measuring, because ultrasonic sensor has some following limitations: low sampling rate, short detection range, and vulnerable to environmental noise. To overcome these limitations, the goal of this research is proposing new operating algorithm for ultrasonic sensors and examining the algorithm in real time by comparing with the conventional algorithm. The proposed algorithm can improve sampling rate of ultrasonic sensor highly. As a result, signal to noise ratio (SNR) is enhanced largely and detection range also becomes longer compared to conventional operating algorithm.**

Keywords– *ultrasonic sensor; low cost sensors; SNR; PPM(pulse position modulation);*

I. INTRODUCTION

Until now, sensors such as stereo camera, lidar, and radar systems have been largely used when measuring distance. They are very accurate to measure the distance, though, there are several disadvantages with these distance sensors as they are high in price and need complex signal processing algorithms. Therefore, high-performance information processing unit is needed in order to compute complicated calculation in real time, which incurs more costs [1], [4]. By the way, ultrasonic distance sensor is inexpensive and even low-performance processor could enough to get distances [6]. But it has disadvantages of relatively short detect range and weakness in surrounding noise [3]. Moreover, ultrasonic distance sensor has much lower sampling rate than the others, so it is hard to apply high speed applications. For these reasons, ultrasonic distance sensors have been used finitely like parking assistant or short range detection applications for indoor mobile robot until these days.

Up to now, there have been attempts to develop the new algorithm of ultrasonic distance sensor. The obstacle detection system of a robot senses obstacle omni-directionally by installing ultrasonic sensors around the robot [2]. However, there are problems of interference of each ultrasonic sensor. Thus, sensors should have peculiarity by having own random sequence of transmitting ultrasonic wave so called chaotic pulse position modulation(CPPM) [7]. Add to this, the duration of each ultrasonic wave can be additionally modulated to enhance the uniqueness of each ultrasonic wave(CPPWM) [8].

The aim of CPPM or CPPWM was suppressing crosstalk effect in multi-ultrasonic sensor system. The unique random sequence of sound pulses was used to differentiate each ultrasonic transmitter-receiver pair. Thus, the entire sequence of pulses must be used altogether which generates a sensing time delay of the sequence length. However in this research, the aim of sequential firing is to increase sampling rate using only one transmitter-receiver pair, so crosstalk is not to be concerned. Each sound pulses in the sequence is treated individually, not altogether.

In this paper, therefore, a novel operating algorithm for ultrasonic distance sensor is proposed. Also, the algorithm is verified experimentally. This paper shows that the algorithm enhances not only sampling rate, but also SNR(Signal to Noise Ratio) performance. Thus, elongation of maximum detection range can be obtained due to increase of SNR. Therefore, the algorithm makes the sensor more robust in the dynamic environments.

The remainder of this paper is organized as follows: In section II, hardware system is presented, followed by the description of the proposed ultrasonic distance sensing logic in section III. Finally, this work is concluded with results in section IV.

II. HARDWARE SYSTEM DESCRIPTION

The hardware diagram is described in Fig. 1. It is consisted of ultrasonic transmitter and receiver respectively. In addition, there are analog signal enhancer for signal conditioning circuit for analog data, and micro controller is used for signal processing and printing out the distance between sensor system and targets.

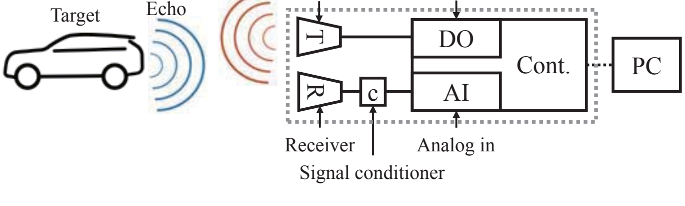

Fig. 1. The diagram for ultrasonic distance sensor system. It is composed of ultrasonic transmitter, ultrasonic receiver, signal conditioner, and MCU.

978-1-4799-8287-5/16/$31.00 ©2016 IEEE

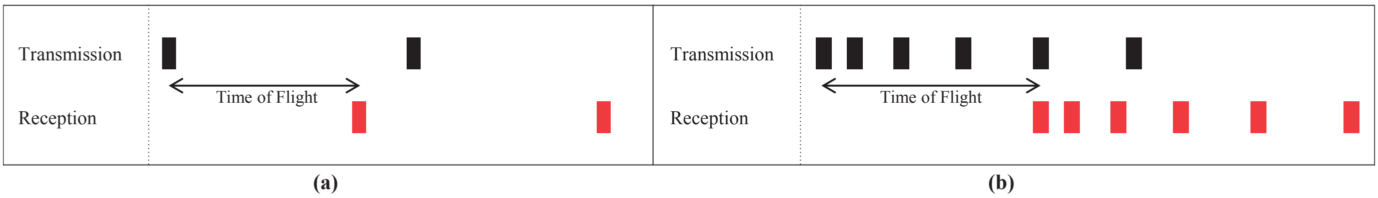

Fig. 2. Both figures show ultrasonic transmission and reception signals with time. (a) is a traditional transmitting method. The ultrasonic distance sensor transmit each sound pulse after reception of the last pulse echo. This method cannot make a transmission pulse until the echo comes back. (b) is the proposed transmission method. The sensor transmit ultrasonic sound pulse regardless of the echo. Each sound pulse is characterized by its interval from the last pulse.

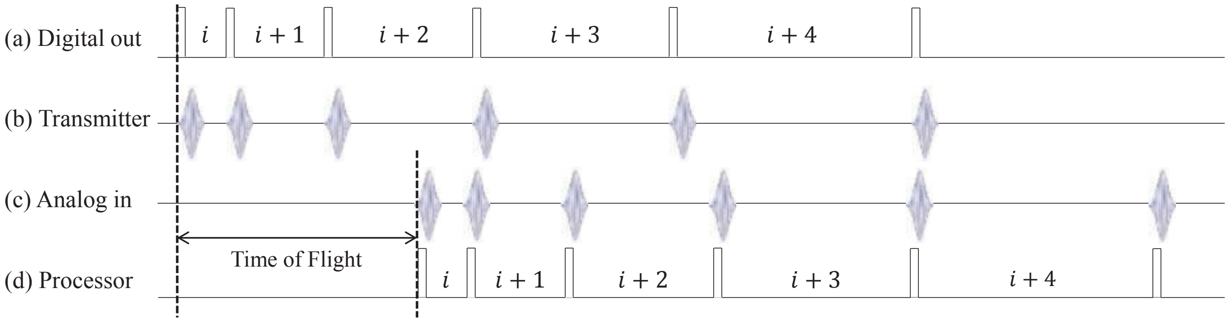

Fig. 3. It shows signals with time in each step of signal processing. The sensor controller generates digital signals which activate ultrasonic transmitter to create ultra sound pulse. The transmitter fires ultrasonic sound pulses which follow the digital out signals. The receiver takes the echoes from the target which always have time-of-flight information. Received raw data enter the processor through signal conditioner which blocks DC component signal and amplifies the signal. And, the processor generates binary information by analyzing the received signal.

III. RANGE MEASUREMENT SCHEME

Ultrasonic sensors usually use ToF (Time-of-Flight) method which measures flight time of waves to measure the distance [5]. This simple logic has critical disadvantage that the sensor module must wait until the echo wave comes back where the signal is transmitted. Therefore, if the echo disappears by noise or environmental reasons, the sensor must wait until the of next ultrasonic transmission as shown in Fig. 2(a). This phenomenon inevitably makes the sensor system idle state.

The proposed novel algorithm for ultrasonic distance sensor dramatically increases sampling rate by eliminating this unnecessary waiting time, thus it can increase the sensor SNR. However, simply increasing the transmission rate could make a problem. The specificity of each sound pulse is needed to distinguish each pulse. To deal with this problem, the proposed logic transmits the sound pulse according to the determined time intervals.

If sound pulses transmitted with chosen time intervals, received signals also have the similar time intervals. Then each sound pulses can be distinguishable with the unique time interval that each pulse has. Thus, a specified transmission interval sequence assigns a signature to each sound pulses as shown in Fig. 2(b).

The transmission interval sequence is shown in Fig. 3. The initial interval starts with ims interval and increases with determined increment. In this research, the transmission interval increases from $3ms$ to $11ms$, in increments of $1ms$. The maximum measurable back and forth distance of usual ultrasonic sensor is $10m$, so the sum of the intervals from $3ms$ to $11ms$, which makes $63ms$, is enough if it is a little larger than ToF of $10m$-round trip, $59ms$. This is a sequence of transmission intervals, and after a sequence ends, the transmission interval sequence restarts from its first interval ims, $3ms$ in this research. The variation of interval sequence is possible depending on the performance of the sensor specifications.

Ultrasonic transmitter generates pulses according to the sequence of digital out signals. The echo of the sound pulses is returned from the target to the receiver. The received signals would become much weaker, so signal processing is an essential process. The sensor controller receives the conditioned echo signals and calculate the distance by comparing the received signal and transmitted sequence. The distance between sensor module and obstacle d is calculated by following well-known formula.

$$d = v_s \cdot t_{tof}/2 \tag{1}$$

where v_s is the velocity of sound and t_{tof} indicates the flight time of sound wave which is measured through this system.

Figure 4 shows the proposed operating logic for enhancing SNR in ultrasonic distance sensor. The transmission algorithm and reception algorithm works in parallel.

In the transmission algorithm, in detail, the transmitter generates first sound pulse(S110) and initial transmitting interval is set to ims, $3ms$ in this research(S120). The reason is that the performance of sensor has limited specification. It is better that setting initial interval as short. And then, the processor saves the transmitting interval(S130) and transmits second pulse after the initial transmission interval time(S140). The processor saves the transmitting interval(S130) again, fires the second sound pulse(S140), and pluses $1ms$ to the interval(S150, S160). The processor repeats this cycle until the

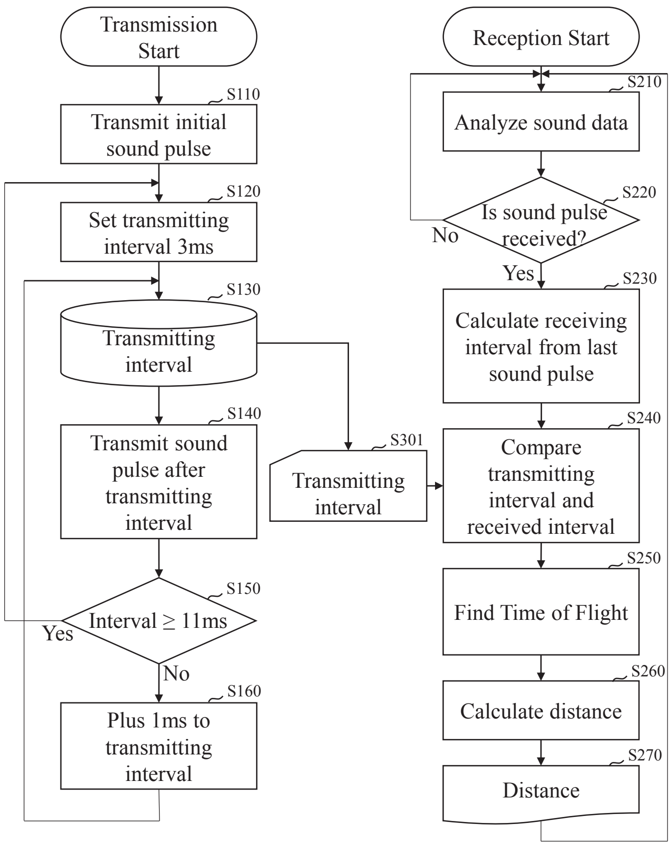

Fig. 4. Flow chart of the proposed ultrasonic distance sensing algorithm.

final interval, $11ms$ in this research. After then, the interval set is returned to the initial interval ims(S120).

The reception algorithm works in parallel with the transmission algorithm. The sound receiver and processor listen all the time whether the echo came back from the target(S210, S220). If a sound pulse is received, the processor determines the interval from the sound pulses(S230). To calculate the ToF, the processor determines when the echo sound pulse is transmitted, by comparing the interval of the received pulse and the transmission interval(S240, S301). If the time-of-flight is determined(S250), the processor calculates the distance(S260) and prints out the distance(S270).

IV. RESULT AND CONCLUSION

The proposed ultrasonic distance sensor working algorithm makes sampling rate and SNR higher, because the system does not have to wait for the flight time of the sound pulse any more.

In this research, transmission interval increases from $3ms$ to $11ms$ and this interval set shows sampling rate about $143samples/sec$. As shown in Fig. 5, the experimental sampling rate would be increased with 1.7 times at $2m$ target, 2.7 times at $4m$, and 2.5 times at $6m$, compared with the traditional operating algorithm.

The increase of sampling rate enlarges the SNR and enables signal gathering even at extended target distance. From the experiment, a simple ultrasonic sensor which has maximum sensing distance of $4.5m$, can detect $8.4m$ target in longest case. This result implies that the performance of the sensor system is much improved by changing the operation software only, which can reduce the additional cost that could arise from upgrading the hardware.

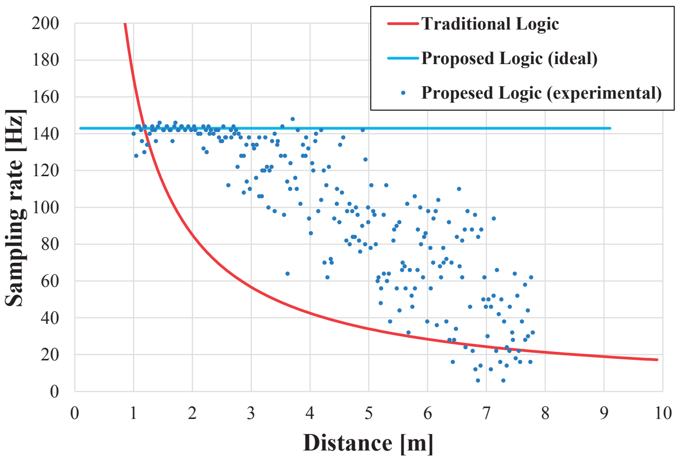

Fig. 5. Sampling rate of traditional and proposed algorithm with experimental data. Each dot represents sampling rate of that time instant from the experiment. They are scattered and as the target distance increases, sampling rate decreases due to the environmental noise.

The algorithm would get better performance in mobile robot and automobile field. Robust frontal distance sensing is possible due to improvement of sampling rate and detection range.

ACKNOWLEDGMENT

This work was partly supported by the Technological Innovation R&D program of SMBA (S2341501) and the Ministry of Trade, Industry & Energy(MOTIE), Korea Institute for Advancement of Technology(KIAT) through the Encouragement Program for The Industries of Region.

REFERENCES

[1] K.-T. Song and W.-H. Tang, Environment perception for a mobile robot using double ultrasonic sensors and a CCD camera, IEEE Trans. Ind. Electronics, vol. 43, no. 3, pp. 372-379, Jun. 1996.

[2] D. Bnk, A Novel Ultrasonic Sensing System for Autonomous Mobile System, IEEE Sensors Journal, vol. 2, no. 6, pp. 597-606, Dec. 2002.

[3] M.-H. Kim, S. B. Choi, Road Surface Height Estimation for Preview System using Ultrasonic Sensor Array" FISITA 2016: Proceedings of the 2016 World Automotive Congress. FISITA, 2016.

[4] K.-T. Song, C.-H. Chen, and C.-H. C. Huang, Design and experimental study of an ultrasonic sensor system for lateral collision avoidance at low speeds, in Proc. IEEE Intell. Vehicles Symp., Parma, Italy, 2004, pp. 647652.

[5] A. Hernndez, J. Urea, J. J. Garca, M. Mazo, D. Hernanz, J.-P. Drutin and J. Srot, Ultrasonic ranging sensor using simultaneous emissions from different transducers, IEEE Trans. Ultrason. Ferroelectr., Freq. Control, vol. 51, No 12, pp. 1660-1670, Dec. 2004

[6] M.-H. Kim, S. B. Choi, Estimation of Road Surface Height for Preview System using Ultrasonic Sensor. IEEE 13th International Conference on Networking, Sensing, and Control.

[7] L. Fortuna, M. Frasca, and A. Rizzo, Chaotic pulse position modulation to improve the efficiency of sonar sensors, IEEE Trans. Instr. Meas., vol. 52, no. 6, pp. 1809-1814, Dec. 2003

[8] Z.-J. Yao, Q.-H. Meng, G.-W. Li, and P. Lin, Non-crosstalk real-time ultrasonic range system with optimized chaotic pulse position-width modulation excitation, Proc. IEEE Int. Ultrason. Symp., pp. 729-732. 2008