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Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 89-90
8-10 November, 2011

Basic Study of Distance Measurement and Movement Detection in Sensor Network Using Ultrasonic Technique
超音波技術によるセンサネットワーク用距離計測と動き検知の基礎研究

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1. Introduction

Sensor network which connects many sensors via small-scale private wireless network such as ZigBee has been researched all over the world. This system consists of many sensors (sensor nodes) which measure environmental parameters such as temperature, humidity, brightness etc. and one controller (center node) which processes the data gathered from all sensor nodes via wireless communications medium. In near future, the sensor network will provide home/office-circumstance monitoring functions such as taking care of old people, preventing crime and maintaining security. Therefore, it is necessary for the system to install not only sensing functions for temperature, humidity etc. but also those for distance measurement and movement detection. In this paper, we will present new method for distance measurement and movement detection.

2. Proposed method for distance measurement and movement detection

Extreme low-power consumption is required for each sensor node in the sensor network. A conventional pulse-echo method cannot be adopted in this system because the transmitter circuit must handle rather high-voltage pulses. Our proposed method is as follows:

(1) Sensor nodes alternatively transmit and receive small-amplitude continuous ultrasonic wave (CUWs), whose frequencies are corresponding to those of IFFT.
(2) Relative amplitudes and phases between the received CUWs and the transmitted CUWs from a certain sensor node are measured in other sensor nodes. These data are sent to the center node.
(3) In the center node, the above data are compensated with phase characteristics of the transmitter and receiver transducers.

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(4) Impulse responses which include distance information between the transmitter and receiver nodes can be obtained using the compensated data by IFFT.
(5) Accurate distance measurement can be achieved by the above procedure. Difference between two impulse responses at different points in time can provide movement information from one point to the other in time.

3. Experiment for accurate distance measurement

Experimental set-up with transmitter and receiver is schematically illustrated in Fig. 1. Amplitude and phase characteristics of only the transmitter / receiver transducers, that is L=0 in Fig. 1 are shown in Fig. 2(a). The impulse responses obtained by IFFT are shown in Fig. 2(b), which indicates that about 10cm null distance is produced due to energy stored effect of the transducers. So the phase compensation for data is essentially important to achieve accurate measurement. Phase-compensated amplitude / phase characteristics with L=50cm are shown in Fig. 3(a). The impulse responses obtained by IFFT and magnified view around the center are shown in Fig. 3(b). In this case, 50cm is exactly measured with error less than 1.5mm.

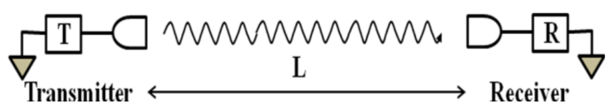
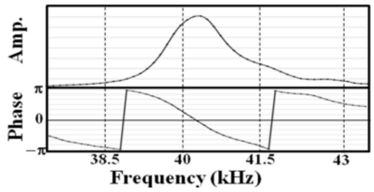


Fig. 1 Experimental set-up with transmitter and receiver.

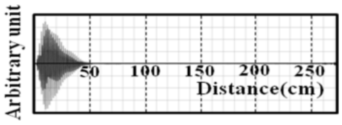
4. Simulation results for detection of movement

If we introduce the proposed method to sensor network as shown in Fig. 4, the impulse responses between transmitters and receivers (sensor nodes) include distance information from nodes to objects.

However there are many reflecting objects, which reveals that exact distances between them and nodes cannot be obtained. If we subtract the impulse responses at present from those at the preceding time, we can obtain the change of distances between objects and nodes at two different points in time. By this procedure, we can exclude effects of inactive objects and can emphasize only moving objects.

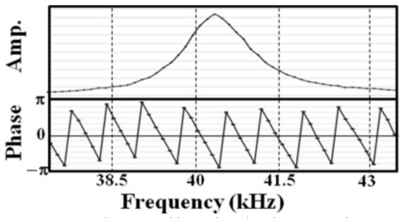


(a) Amplitude /phase characteristics.

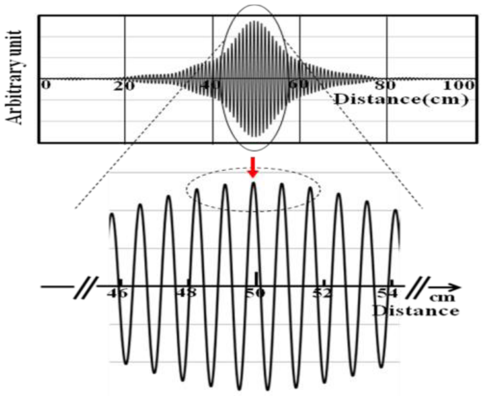


(b) Impulse responses

Fig. 2 Characteristics of only transmitter and receiver transducers (L=0).



(a) Measured amplitude / phase characteristics.



(b) Impulse responses and magnified view.

Fig. 3 Experimental results with phase compensation for distance of L=50cm.

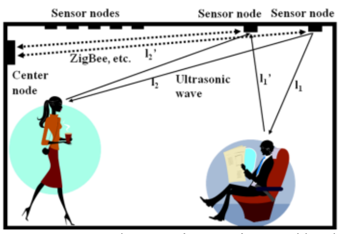


Fig. 4 Movement detection installed in sensor network.

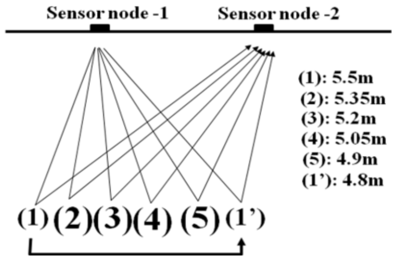
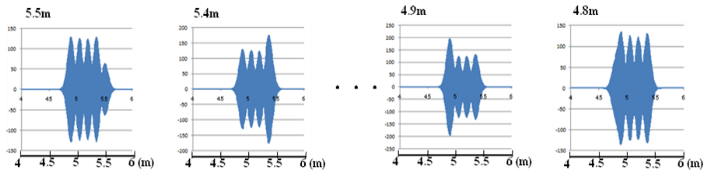
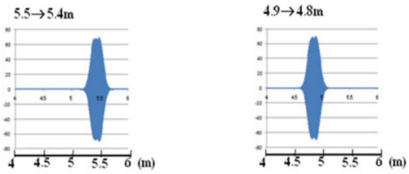


Fig. 5 Simulation model with moving object from (1) to (1').



(a) I.R.(5.5m) (b) I.R.(5.4m) (c) I.R.(4.9m) (d) I.R.(4.8m)

Fig. 6 Impulse responses for object with distances of 5.5-4.8m.



(a) I.R.(5.4m)-IR(5.5m) (b) I.R.(4.8m)-I.R.(4.9m)

Fig. 7 Subtraction of Figs. 6's impulse responses between two points in time. They correspond to movements of object.

A simulation model is shown in Fig. 5, where one object at the position (1) with 5.5m distance moves to the position (1') with 4.8m distance. There are other 4 reflecting objects in this model. The simulated impulse responses at the positions with 5.5-4.8m distances are shown in Fig. 6(a)-(d). Subtracting to each other between two impulse responses at two different points in time clearly illustrates movement of the object as shown in Fig. 7(a) and (b).

5. Conclusion

We have proposed a new ultrasonic accurate distance measurement method based on impulse responses calculated by IFFT procedure. Experimental results show the validity of our proposal. Assuming the future sensor network, we investigate movement detection using the method. Simulation results show that only moving object can be detected.

References

1. W. Dargle, et al, "Fundamentals of wireless sensor networks," John Wiley and Sons, 2010.