Sensors Network for Ultrasonic Ranging System

Tao Gao, Department of Automation, North China Electric Power University, Baoding, China
Zhenjing Yao, Department of Disaster Prevention Instrument, Institute of Disaster Prevention Science and Technology, Beijing, China

ABSTRACT

The spectrum matching and correlation characteristic are both important in the multiple-user ultrasonic ranging system. As people know, an ultrasonic ranging system, which has a bell-shaped magnitude spectrum, acts like a band-pass filter. If the spectrum of the excitation signal does not match that of the ultrasonic ranging system, some of energy cannot be transmitted by the ultrasonic system. In other words, it does not make full use of the bandwidth of the ultrasonic ranging system. The good correlation characteristics can eliminate cross-talk among multichannel ultrasonic sensors firing simultaneously. To the authors’ knowledge, not many researchers considered how to make the spectrum of the excitation sequence match to that of the ultrasonic ranging system as well as improve the correlation characteristics. In this paper, the chaotic frequency modulation (CFM) excitation sequences are proposed for multiple-user ultrasonic ranging system. To obtain the excitation sequences which are spectrally matched to the ultrasonic ranging system as well as have the best correlation characteristic, the NSGA-II is applied to optimize the CFM excitation sequences.

Keywords: Chaotic Frequency Modulation (CFM), Linear Frequency Modulation, Sensors Network, Spectrum Matching, Ultrasonic Sensor Ranging System

1. INTRODUCTION

Ultrasonic sensors have been widely used for distance measurement and obstacle avoidance because of their small size, low price and simple hardware interface. To obtain 360° panorama distance information, an ultrasonic ranging system consisting of multichannel ultrasonic sensors is required (Moravec H., 1988). One problem with such sensors in an ultrasonic ranging system operating in close proximity is the well-known crosstalk phenomenon, where one ultrasonic sensor receives echoes transmitted by another ultrasonic sensor (Meng Q., Yao F., Wu Y, 2006). Usually, the ultrasonic receiver cannot judge whether the received echo is created from its own transmission or not, so false time-of-flight (TOF) measurement often occurs. In order to avoid ultrasonic crosstalk, most ultrasonic ranging system triggered their sensors sequentially (Hori, T., Nishida, Y., Kanade, T., & Akiyama K, 2003), which limit the work efficiency of the ultrasonic ranging system.

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To eliminate the ultrasonic crosstalk, some researchers adopted different code and modulation schemes constructing excitation sequence to assign each ultrasonic sensor a recognizable signature. Jörg and Berg (1998) first applied pseudorandom sequences to give each ultrasonic sensor a marker. A matched filter in the receiving circuit then identified the associated source sensor. Ureña and his colleagues (Ureña J., Mazo M., García., Hernández Á., & Bueno E, 1999) used a 13-bit Barker code to construct their excitation sequences for ultrasonic sensors. While the available Barker codes limit their application. Golay codes (Hernández Á., Ureña J, & Hernanz D., 2003; Ding Z., & Payne P, 1990; Hernández Á., Ureña J., & García J, 2004; Alvaréz F., Ureña J., Mazo M., 2004; Diaz V., Ureña J., & Mazo M., 1999; Marziani C., Ureña J., & Hernández A., 2007) were applied in ultrasonic ranging system to avoid crosstalk and increase the signal to noise ratio (SNR). Chaotic codes (Fortuna L., Frasca M., & Rizzo A, 2003; Yao Z., Meng M., Li G., & Lin P, 2008) were also used to eliminate crosstalk in multichannel simultaneously triggered ultrasonic ranging System. Fortuna et al. (2003) exploited chaotic pulse position modulation (CPPM) to fire the ultrasonic sensor. Yao et al. (Yao Z., Meng M., Li G., & Lin P, 2008) proposed chaotic pulse position width modulation (CPPWM) excitation sequences as the transmission sequences of ultrasonic sensors. Nakahira (Nakahira K., Kodama T., Furuhashi T., & Maeda H, 2005) used binary-coded frequency-shift keyed signals to drive ultrasonic sensors to eliminate crosstalk. Meng et al. (2005, 2006) proposed pseudorandom frequency modulation and frequency-hopping pseudorandom pulse-width modulation sequences to excitation ultrasonic sensor, and the result of avoiding crosstalk was not good. The signals with linear frequency modulation (LFM) (Pollaskowski M., 1993-1994) were used as the transmission signals of ultrasonic sensors, which could avoid crosstalk. But the spectra of LFM excitation sequences are not totally matched to that of the ultrasonic ranging system. And the number of available LFM excitation sequences is limited because of the narrow bandwidth of the ultrasonic ranging system. In order to make the spectrum of excitation sequence match to that of the ultrasonic ranging system, Pollatowski and Ermert (Pollakowski M., & Ermert H, 1994) applied transmitter signals with a constant amplitude level and nonlinear frequency modulation. However, they did not research how to obtain the good correlation characteristics of the excitation sequences.

Optimization techniques have also been applied to construct excitation sequences in multichannel ultrasonic ranging system. Griep et al. (1995) adopted a global optimization technique to select proper coding signal for multiple-user ultrasonic ranging system. Osamu Hikino and his colleagues (Hikino O., Belkerdid M., & Malocha D, 2000) optimized PN sequences to reduce autocorrelation function’s side-lobe. Nakahira et al. (2005) used a combination of simulated annealing and hill climbing to minimize the peaks in the cross-correlation function as well as minimize the maximum side-lobe in the autocorrelation function. Meng et al. (2009) applied a genetic algorithm (GA) to optimize short CPPM and pseudorandom PPM triggering sequences in order to improve correlation characteristics (i.e. minimize the side-lobe in the autocorrelation function and the peaks in the cross-correlation function). Yao et al. (2008) adopted nondominated sorting genetic algorithm II (NSGA-II) to optimize CPPWM excitation sequences in order to sharpen the autocorrelation and flatten the cross-correlation as well as to maximize echo energy.

Both the spectrum and correlation characteristics are important in constructing excitation sequences to realize the multichannel ultrasonic sensors working together. For LFM excitation sequence, there should not be too many simultaneously fired ultrasonic sensors, because of the limited available frequency band of the ultrasonic ranging system. The optimized CFM excitation sequences are proposed to trigger multiple-user ultrasonic sensors in this paper. Comparing with the CFM excitation sequences without optimization, the NSGA-II based optimization CFM excitation sequences
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