Indoor Positioning using Ultrasonic Waves with CSS and FSK Modulation for Narrow Band Channel

Alexander Ens, Fabian Hoeflinger and Leonhard Reindl
Laboratory for Electrical Instrumentation (EMP)
Department of Microsystems Engineering (IMTEK)
University of Freiburg, Germany
Email: alexander.ens@imtek.uni-freiburg.de

Johannes Wendeberg and Christian Schindelhauer
Chair for Computer Networks and Telematic (CONE)
Department of Computer Science (IIF)
University of Freiburg, Germany
Email: wendeber@informatik.uni-freiburg.de

***Abstract*—We propose a transmission scheme for localization based on the exchange of data between the transmitter and receiver. The ultrasonic signal is used twice, first for indoor localization by synchronization of the transmitter with the receiver and second to transmit additional information to improve the localization.**

Our approach for coding the information is a combination of chirp spread spectrum (CSS) signals and frequency shift keying (FSK) to method avoids fast phase changing and shifts of the ultrasonic wave, which results in narrow band characteristic.

***Index Terms*—FSK; CSS; Ultrasonic; Communication; Localization**

I. Introduction

In our everyday life it is important to know the actual position of things. The interests for localization services are growing and there is huge amount of possible applications, e.g. as navigation of shopping carts in super markets. Localization systems based on ultra-sonic are very cheap, have a low complexity compared to radio frequency and good position accuracy is with simple hardware possible, too. While the speed of sound is about 10^6 times slower than the speed of light, the position can be determined by time delay of arrival (TDOA) methods with low sampling rates of the received signal and without an additional intermediate frequency mixer.

The disadvantage of ultrasonic is the absorption and therefore the attenuation of the transmitted signal by the air. Furthermore the attenuation in the environment depends on temperature and humidity of the air. Also the sound noise from industry and traffic disturb the ultrasonic sound. Another point that should be kept in mind, are the good reflections at walls and plane surfaces that cause additional echoes, which disturb the signal and reduces the signal-to-noise ratio (SNR) at the transmitter.

To overcome the absorption of the air, the use of low frequency for the transmission can be used [1]. To avoid the distortion of the signal by echoes, a guard interval is used to have a silent pause before the next signal is transmitted.

A simple localization system has one transmitter and at least three receivers to determine the position by TDOA in 2D of the transmitter. To distinguish between more than one transmitter, the transmitted signals need additional information of the signal origin and therefore the identification of the transmitter. Then the receiver can determine the origin of the signal and map the time of arrival to the transmitter. The calculation of the position is augmented from the TDOA problem to data transmission and TDOA.

A possible solution is, to give each transmitter a different frequency band. Yet, this is very expensive, because of the need of a broad band receiver and the limited free frequency bands. Another modulation scheme is the chirp spread spectrum (CSS) [2]. The chirp modulation avoids destructive interference of the echoes at the receiver by linear frequency modulation and therefore the signal can't disappear at the receiver. Another advantage of the CSS is the robustness against the Doppler shift and good detection of the center of the chirp sequence by correlation. The CSS modulation needs fast Phase changes and therefore a higher bandwidth. The Gaussian Minimum Shift Keying (GMSK) overcomes the problem of fast phase switching by rounding the phase transitions [3].

II. System Description

In our measurement setup we place the receiver at the top and the transmitters are mobile robots. The position of the receiver is known and the position of the signal origin can be calculated by established TDOA algorithms.

The used narrow band transmitter device has its resonance frequency at about 39 kHz and the receiver at about 41 kHz. Therefore to get the maximum of the transmission devices a band of 2 kHz will be used.

The symbol set consists of two continuous sinuses with constant frequency and f_0 and f_1, an "up" chirp and a "down" chirp. The symbol length is the inverse of the used frequency bandwidth: $T = \frac{1}{\Delta f} = 0.5$ ms.

The first symbol in the frame is for precise synchronization and therefore this symbol is only used at the beginning of the frame. The synchronization symbol is an "up" and "down" chirp in the duration of a symbol. The next symbol is an "up" chirp for logic 1 or a constant sinus with frequency f_0 for logic 0. The followed symbol depends on the previos symbols. The Table I below shows the mapping of the symbols depending on the previous symbol. So the data is coded in the frequency by constant sinus or in chirps. The modulation of the frequency over time for the Bit sequence 0011000 is shown in figure 1.

Instead of using two frequency sources for the FSK, we use only one sinus source and change the phase slope smoothly.

Previous Data Bit	Current Data Bit	Symbol
0	0	Constant sinus with frequency f_0
0	1	"Up" chirp from frequency f_0 to f_1
1	0	"Down" chirp from frequency f_1 to f_0
1	1	Constant sinus with frequency f_1

Table I
SYMBOL MAPPING FOR COMBINED FSK AND CSS MODULATION

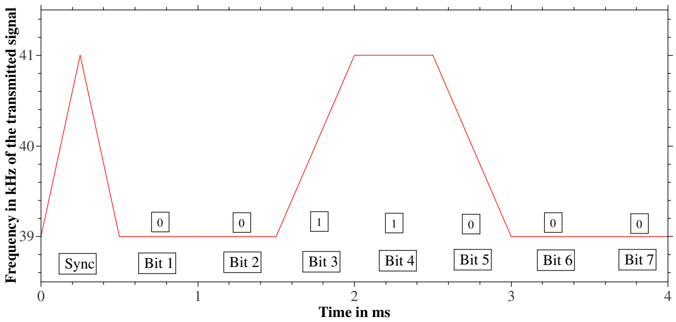

Figure 1. Combined CSS and FSK modulation for Bit sequence 0011000

III. SIMULATION RESULTS

The needed bandwidth of the transmission scheme is simulated by 10'000 frames with 20 symbols for the combined modulation of FSK and CSS and pure CSS modulation in figure 2. The black line is the measured ultra-sonic channel (includes transmitter and receiver) by a vector analyzer. The power spectrum of the combined modulation (blue dashed line) fits very well to the channel characteristics (black line).

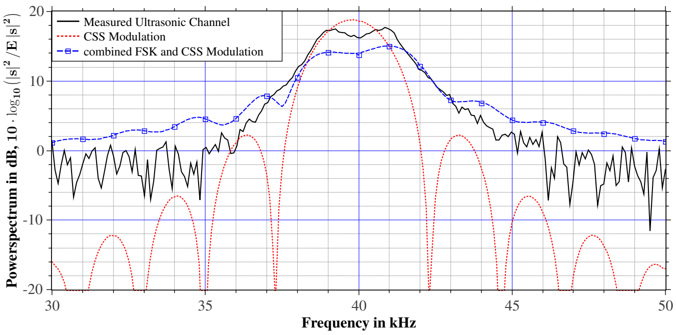

Figure 2. Bandwidth comparison of CSS Modulation and proposed modulation with FSK and CSS

The spectrum of the received signal is the multiplication of the channel spectrum and the modulated signal spectrum. The result is a Gaussian like shape of the spectrum. This is because the shape of the combined modulation spectrum has, unlike the CSS spectrum, not the periodic minima of the sinc pulse. One of the important property of the Gaussian shape in the frequency domain is the minimized time-bandwidth product [4].

A further simulation shows in figure 3 the bit error rate (BER) over the energy-per-bit and noise power. The BER for the combined modulation is exactly between the bipolar modulation, like binary orthogonal Keying (BOK) CSS [5], and the unipolar modulation, like On-Off-Keying (OOK) [4]. The gain is about 1.5 dB to unipolar modulation. The reason therefore is that, the chirp signal is not orthogonal to the constant sinus signal.

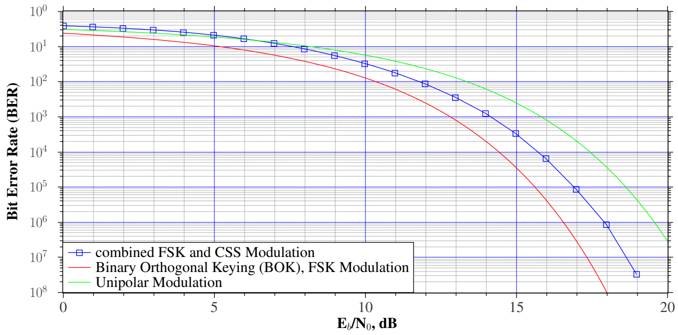

Figure 3. Bit Error Rate over Bit-Energy per Noise power

IV. CONCLUSION AND DISCUSSION

In this paper, we presented a combined FSK and CSS transmission scheme for the available bandwidth without frequency shifts and smoothly phase changes.

The bit error rate can be further decreased by applying the Viterbi algorithm to estimated data. Then the correlation coefficient between the signal and the symbol set can be used as a metric for the path calculation in Trellis diagram.

Furtermore, the synchronization can be extended to synchronize over all sweeps in the signal. This can further improve the synchronization and the localization accuracy.

ACKNOWLEDGEMENT

We gratefully acknowledge financial support from "Spitzencluster MicroTec Suedwest" and BMBF.

REFERENCES

[1] "ISO 9613-1:1993, acoustics – attenuation of sound during propagation outdoors – part1."
[2] A. J. Berni and W. Gregg, "On the utility of chirp modulation for digital signaling," *IEEE Transactions on Communications*, vol. 21, no. 6, pp. 748–751, 1973.
[3] K. Murota and K. Hirade, "GMSK modulation for digital mobile radio telephony," *IEEE Transactions on Communications*, vol. 29, no. 7, pp. 1044–1050, 1981.
[4] J.-R. Ohm, *Signalübertragung: Grundlagen der digitalen und analogen Nachrichtenübertragungssysteme*. Berlin [u.a.]: Springer, 2005.
[5] A. Springer, W. Gugler, M. Huemer, L. Reindl, C. Ruppel, and R. Weigel, "Spread spectrum communications using chirp signals," in *EUROCOMM 2000. Information Systems for Enhanced Public Safety and Security. IEEE/AFCEA*, 2000, pp. 166–170.