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Demo: A Case for Chirp Modulation for Low-Power Acoustic Communication in Shallow Waters

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***Abstract*—Small and cheap micro AUVs enable diverse underwater monitoring applications in shallow inshore waters; e.g., inspection of underwater assets, observation of water quality, and identification of pollution sources. The formation and collaboration of swarm members yet requires communication and self-localization based on cheap, miniature acoustic devices. However, this is severely hampered by the effects of multi-path propagation in shallow waters. We study the benefits and applicability of narrow-band chirp-based modulation vs. frequency-shift keying (FSK).**

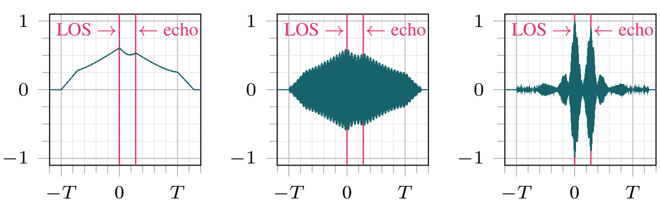
I. Introduction

Exploration and monitoring of underwater sceneries is drawing considerable attention. Recent examples are the investigation of sub-mesoscale eddies [1] or ship tracking in harbors [2]. Timely acquisition of data mandates communication—typically wireless to keep installation and maintenance cost low. Shallow and relatively small water bodies—such as port basins, lakes, or canals—are a particularly challenging scenery. Reflections at the water surface cause massive inter- and intra-symbol interference, because the non-line-of-sight (NLOS) signals have a low delay and attenuation only [3]. In previous research [4] and recent measurement campaigns, we experienced significant attenuation and amplification of frequency shares depending on position and time. In addition, we noted influence of environmental conditions and their change over time. As a counter measuring we embark on the use of narrow-band chirp signals for preamble-based synchronization, motivated by the following observations. We noted that communication with our acoustic modem was—despite using FSK modulation—reliable, if the preamble was successfully detected by the receiver. Failure to do so arises mainly from cancellation and amplification caused by reflections and scattering. The main reason for this is intra-symbol interference leading to unreliable symbol detection and hence synchronization. Once the synchronization has succeeded, however, the symbol windows are known and reliable communication can be achieved through relatively simple methods such as frequency hopping and redundancy coding.

II. Fundamentals

A. Frequency-Shift Keying

Frequency-Shift Keying (FSK) is commonly used in acoustic underwater communication. In binary frequency-shift keying (BFSK), a bit b is transmitted as a sinusoidal symbol with



(a) FSK non-coherent (b) FSK cross-corr. (c) chirp cross-corr.

Fig. 1: Detection of chirp ($f_s = 50\,\text{kHz}$, $f_e = 54\,\text{kHz}$) and FSK ($f = 50\,\text{kHz}$) signal superimposed by an echo with $0.7\,\text{ms}$ delay and 90% amplitude (ca. $10\,\text{m}$ distance at $2\,\text{m}$ depth). Symbol duration is $T = 2.5\,\text{ms}$. Time on the x-axis is relative to perfect LOS detection.

frequency f_b and duration T. There are more complex forms of FSK, which we do not address in detail due to space constraints. Receivers often employ non-coherent detection due to its efficiency, but cross-correlation is also possible. Orthogonal frequencies f_b may improve detection. The (envelope) shape of detector output is trapezoidal for undistorted symbols with constant amplitude, with its peak marking the symbol's end. If reflections overlap with the line-of-sight (LOS) signal, detector output contains overlapping triangles as in Figs. 1a and 1b. Depending on the number and phase of reflections, a clear peak is no longer present, impacting detection accuracy and likelihood.

B. Chirp Keying

A chirp is a signal with steadily changing frequency over time. We consider linear chirps, where the frequency sweeps linearly over time from frequency f_s to f_e. The chirp has duration T and bandwidth $B = |f_e - f_s|$. A bandwidth-efficient way to employ binary modulation is to use down-chirps ($f_s > f_e$) and up-chirps ($f_s < f_e$) to represent bit b. Detection of a chirp can be achieved through cross-correlation. The detector output is a narrow and steep peak, which allows a clear distinction between the LOS signal and reflected signals as displayed in Fig. 1c. Because of this property, chirps are commonly employed in radar applications.

C. Comparison and Discussion

In various real-world experiments [4], we confirmed heavy, time-varying, and location-dependent frequency selectivity of the acoustic channel. This is of paramount relevance for

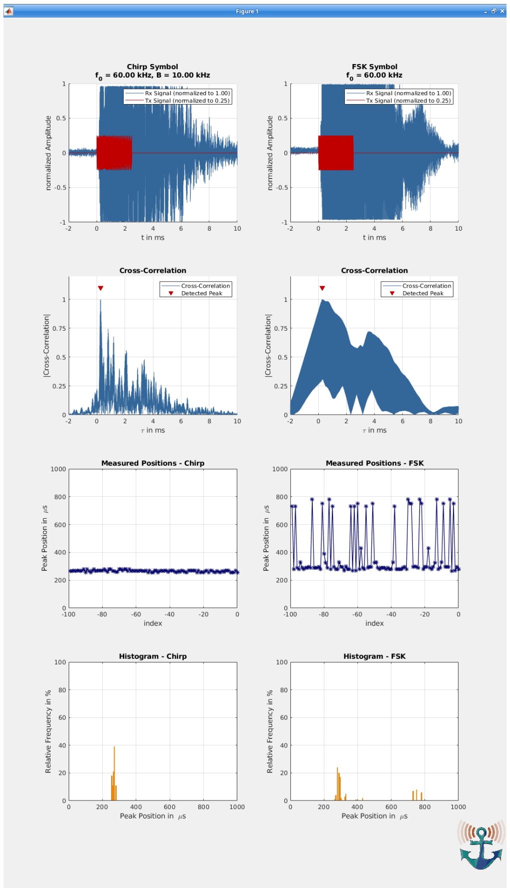


Fig. 2: User Interface of our MATLAB implementation for demo purposes.

preamble-based synchronization. Here, symbol (window) positions are derived by detecting the preamble symbols or their peaks, respectively. For successful packet reception and precise time-of-flight ranging [5], accurate synchronization is mandatory. In case of FSK, signal cancellation and reverberation due to reflections cause poor synchronization. As shown in Fig. 1, the peak of the originally trapezoidal detection result is blurred and accurate detection hampered. Noise and multiple echos aggravate this situation. In case of destructive interference, a peak may not be found at all.

Chirp modulation brings two advantages: (i) its frequency spreading increases detection probability, because attenuation of frequency shares due to reflection is drastically reduced, and (ii) the peaks of the LOS signal and its echos are separable in the time domain, so that a smaller synchronization error is expected. Using chirps yet comes at a cost. The benefit of non-coherent FSK detection is its low computation complexity. For each new sample, two multiplications are required, giving a constant computation complexity per new sample. Without optimization, cross-correlation has to be performed for a full symbol for every sample, yielding at least logarithmic computation complexity per new sample. For low-power acoustic modems, this complexity may already be infeasible. Hence, we study the performance of chirp vs. FSK in general but also discuss the feasibility of chirp detection on low-power acoustic modems.

III. Demo Setup

Details on our implementation and evaluation of chirp keying compared to frequency shift keying are given in the accepted paper. For the demo itself, we use the smartPORT acoustic modem [4], a low-power, low-cost device for use in μAUVs such as Hippocampus [6]. We deploy two hydrophones in a small glass tank with a distance of several centimeters. We send a single symbol, an up-chirp or a FSK symbol. The base frequency and the bandwidth, in the case of an up-chirp, can be adjusted by the visitor during the demo.

Signal generation is done with MATLAB and an external USB oscilloscope and waveform generator TiePie HS5. The generator is connected to the input of the transmit circuitry of the modem. It is amplified and fed to the hydrophone.

The signal, received from the second hydrophone is amplified by the receiver circuit of our modem. We remove the band pass filters to eliminate any influence on the received signal. The output of the analog processing chain is captured with the oscilloscope and plotted in comparison to the transmitted signal with MATLAB.

In addition to that, we show the result of cross-correlation with a stored reference signal to explain the better separability of chirp signals in comparison to a FSK signal. The peak postion in the time domain, detected by our synchronization algorithm is also shown for both modulations and indicates a lower variation using chirp modulation. The interface we use for the demonstration is depicted in Fig. 2.

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References

[1] B. Meyer, C. Isokeit, E. Maehle, and B. Baschek, "Using Small Swarm-Capable AUVs for Submesoscale Eddy Measurements in the Baltic Sea," in *Proc. of the MTS/IEEE Oceans Conf.*, Sep. 2017.

[2] M. Rao, N. K. Kamila, and K. V. Kumar, "Underwater Wireless Sensor Network for Tracking Ships Approaching Harbor," in *Proc. of the IEEE International Conf. on Signal Processing, Communication, Power and Embedded System (SCOPES)*, Oct. 2016.

[3] T. Jenserud and S. Ivansson, "Modeling the Power Delay Profile of Underwater Acoustic Channels — The Effects of Out-of-Plane Scattering and Reverberation," in *Proc. of the International Conf. Underwater Communications and Networking (UComms)*, Sestri Levante, Italy, Sep. 2014.

[4] C. Renner and A. J. Golkowski, "Acoustic Modem for Micro AUVs: Design and Practical Evaluation," in *Proc. of the 11th ACM International Conf. on Underwater Networks & Systems (WUWNet)*, Shanghai, China, Oct. 2016.

[5] C. Renner, "Packet-Based Ranging with a Low-Power, Low-Cost Acoustic Modem for Micro AUVs," in *Proc. of the 11th International ITG Conf. on Systems, Communications and Coding (SCC)*, Hamburg, Germany, Feb. 2017.

[6] A. Hackbarth, E. Kreuzer, and E. Solowjow, "HippoCampus: A Micro Underwater Vehicle for Swarm Applications," in *Proc. of the IEEE/RSJ International Conf. on Intelligent Robots and Systems (IROS)*, Hamburg, Germany, 2015.