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Symmetry Oriented Covert Acoustic Communication by Mimicking Humpback Whale Song

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Abstract: To meet the increasing demand of covert underwater acoustic communication, biologically inspired mimicry communication watermarking the data in symmetrical humpback whale song is presented. Mimicry is an entirely different approach from traditional covert communication where data are transmitted by spreading the waveform at a low signal to noise ratio. In this innovative technique, the carrier signal is imitated symmetrical to the ocean background noise, which can be shipping noise, anthropological noise, or the vocals emitted by sea animals. The eavesdropper can detect the communication signal, but will assume it to be real ocean noise due to its symmetry. It excludes the mimicked signal from recognition, which makes the communication covert. In this research, we watermarked the covert information in humpback whale song using discrete cosine transform in the frequency domain. The mimicked symmetrical signal provided excellent imperceptibility with the real song and an outstanding camouflage effect was calculated. We validated the novel concept by simulation and underwater tank experiment. 10^{-4} BER was achieved in the underwater tank experiment, which was diminished to zero error by using matching pursuit estimation and virtual time reversal equalization. This novel bionic covert communication technique is feasible for clandestine underwater acoustic communication in the presence of an eavesdropper with better imperceptibility.

Keywords: underwater acoustic communication; bionic; covert communication; watermarking; DCT; humpback whale; mimicry

1. Introduction

Transferring information furtively in the underwater acoustic channel is one of the most vital requirements for military, oceanography, defense, and naval operations [1,2]. Transmitting data covertly in the underwater medium is termed as covert underwater acoustic communication (CUAC). The information needs to be kept secret from any eavesdroppers [3], but can be decoded by the intended receiver. A variety of ways have been investigated for CUAC, which includes low SNR communication, encryption, and disguising as sea marine mammals [4,5].

Covert communication can be divided as low probability of detection (LPD) and low probability of interception (LPI) [6]. In LPD communication, the enemy does not know of the existence of the communication and has less chances to perceive the signal. Usually, this is achieved by reducing the

SNR below the noise level. LPI constraint communication allows the communication signal to be sensed by the eavesdropper, who has negligible chances to extract the information from the signal. The information is encoded or watermarked in the communication signal. Our research focused on the LPI constraint communication where the data are watermarked in natural sea sounds. The eavesdropper is tricked as it recognizes the signal as the real sea sound due to its signature. This is termed as low probability of recognition (LPR) constraint communication.

Traditionally, during the last decade, covert communication in the underwater acoustic channel was achieved by shielding the communication signals in background noise by reducing the SNR and modulating the waveform by different modulation methods [7–9]. These techniques have excellent LPD capability, however, when the eavesdropper approaches the transmitter, it can detect the communication signal through an energy detector [10,11] as the SNR is increased by limiting distance. Therefore, the communication cannot be made truly covert for all distances between the transmitter and receiver. Other major drawbacks of this technique include a shorter transmission distance and an extremely low throughput due to low SNR.

To enhance the security and effectiveness of CUAC, biologically inspired communication mimicking natural sea sounds was introduced [5,12,13]. The communication signal is structured analogous to real ocean noise, which can include jingles produced by ships, cetaceans, wind, tides, rain drops, etc. The mimicked waveform can be sensed by an adversary, but it will recognize the signal as a natural sea sound due to its signature. The eavesdropper is tricked and assumes the communication signal to be ocean noise, which means that the communication is made truly covert. Therefore, this technique provides perfect clandestine communication across all communication ranges without reducing the SNR. Thus, CUAC is possible in the presence of eavesdroppers and gives excellent LPR characteristics [4,14].

Sea creatures emit a variety of sounds in a frequency range from 15 Hz–100 kHz. The communication of cetaceans is based on acoustic waves due to less visibility in oceans under ten meters. They produce vocal sounds to identify prey and predators. They also emit sounds for echo localization and social interaction [5]. Cetaceans can be divided into two main groups, namely Mysticeti and Odontoceti. Mysticeti emit vocally at a low frequency with a high source level. Odontoceti emit vocally at a high frequency with a lower source level [15]. In this research, we focused on humpback whale vocals that are in the Mysticeti family. Its sound can be utilized for long range clandestine communication due to its low frequency and high source level. Biologically inspired CUAC can be established by taking advantage of natural cetacean sounds. The information is watermarked in the cetacean vocal by slightly varying a parameter within its operational range.

The first covert experiment using mimicry communication was performed by H.S. Dol et al. and mimicked dolphin sounds [13]. They used whistles and clicks as synchronization and information signals, respectively. Liu et al. also used the clicks of dolphin for clandestine communication [12] where secret information was encoded between the time intervals of the clicks. The data rate of 37 bps was achieved, which was later improved to 69 bps by using the M-ary technique [16]. In [17], dolphin clicks were mimicked to establish furtive communication using time hopping–pulse position modulation (TH–PPM). A. ElMoslimany et al. conducted successful tests for covert communication using the whistles of the dolphin *Lagenorhychus obliquidens* and whale *Globicephala melas* [18]. The minimum shift keying (MSK) modulation technique also uses dolphin whistles for clandestine communication. A 10 bps data rate was achieved with a BER of 10^{-3} [19]. Yin Jing-Wei et al. used dolphin whistles for stealthy covert communication [20,21] where the covert information was watermarked in the interval of whistles.

In this research, we used humpback whale vocals for covert communication due to their natural characteristics. Humpback whales emit a long duration vocal termed as song. The bandwidth of the song lies from 50 to 4000 Hz [22]. We opted for this natural vocal as a carrier for this research due to its frequency and duration [23]. Low frequency allows for a larger transmission distance, which benefits the accomplishment of furtive communication in a bigger region. The long duration of humpback whale song adds a surplus advantage to performing a surreptitious operation for an elongated period. The secret information was watermarked in the natural song in the frequency domain using discrete cosine transform (DCT). The information is spread over the bionic signal and gives excellent imperceptibility. We verified our novel concept in an underwater tank and conducted simulations for long range communication. The novel concept can be applied by a variety of acoustic modems [24] whose frequency lies in the range of humpback whale song.

The rest of this paper is structured as follows: Section 2 addresses the acoustic properties of humpback whales. Section 3 describes the synchronization and watermarking technique using DCT. Imperceptibility and the camouflage effect is estimated in Section 4. Section 5 validates our novel concept through the experiments. Finally, Section 6 concludes the paper and highlights the future research direction.

2. Humpback Whale Song

This section describes the acoustic properties of humpback whale song. The humpback whale *Megaptera novaeangliae* is one the largest sea mammals in the ocean. Male whales are famed for producing loud songs with time durations lasting from several minutes to hours [25,26]. If there was to be a song contest among cetaceans, humpbacks would no doubt emerge victorious [27]. These songs have been and are still being studied extensively, mostly to understand why humpback whales sing. Generally, the male humpback sings the song when swimming alone in the winter breeding season. Smith et al. claims that humpback whales produce songs for intersexual interactions [28], however, the exact purpose of emitting the song has not been clearly defined yet.

Humpback whales may sing the song continuously for hours and the sound is typically composed of fewer than ten themes that are repeated in a particular order during the song. A theme is made up of phrases or sequences lasting about fifteen seconds. Its main energy lies in the bandwidth between 50 Hz–4000 Hz. The source level of the song is measured around 175–188 dB re 1µPa @ lm [29]. We opted to use this unique complex song as a carrier to establish a long transmission distance due to its low frequency and high source level features. The long singing duration of the humpback whale benefits covert operations being conducted for elongated periods. Figures 1 and 2 show a phrase of humpback whale song depicted from the oceans acoustic library [30].

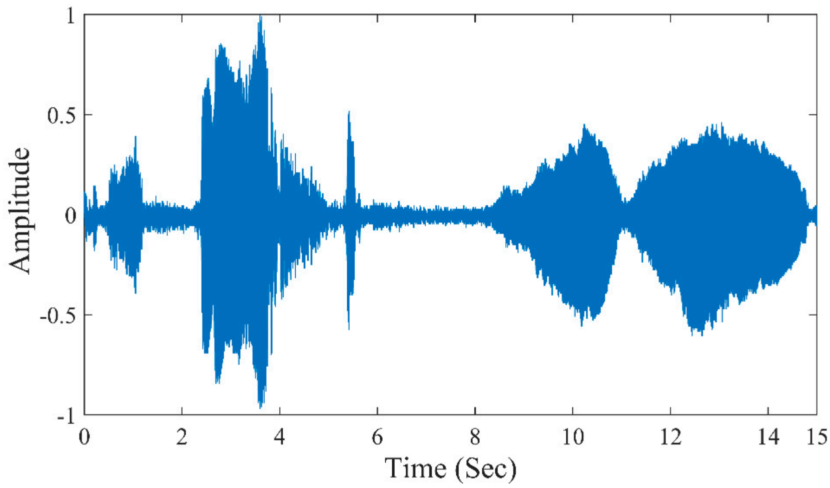


Figure 1. Humpback whale song in time domain.

It can be seen in Figure 1 that humpback whale song has several high amplitude time patches. The main energy duration of song is extracted and the data are watermarked using DCT in the peak positions in the transform domain through a unique way known to the intended receiver. The imitated signal along with the watermarked data looks identical to the real humpback whale sound, thus producing a perfect covert signal.

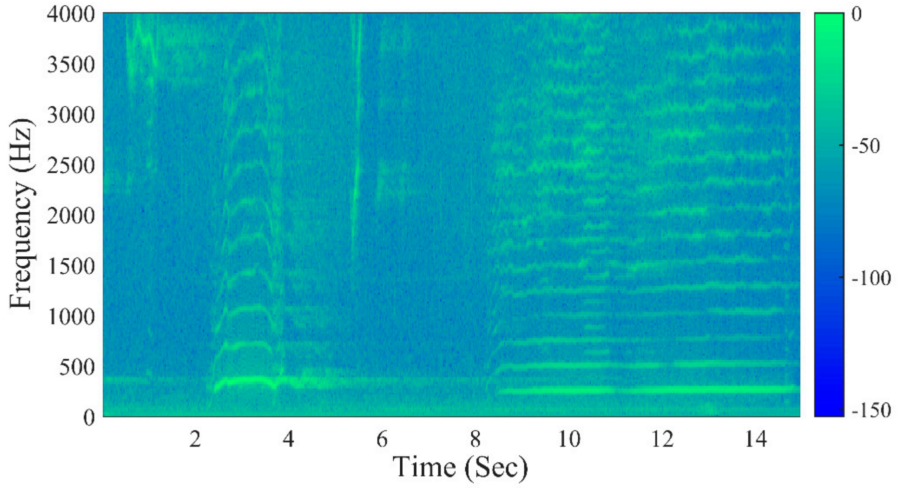


Figure 2. Time frequency representation of humpback whale song.

The frequency spectrum of a real humpback whale song is shown in Figure 2. The song has a wide range of frequencies; however, the main energy lies in the low frequency region around 150 Hz. Due to this feature, humpback whale song can be heard from several kilometers in the ocean. We took advantage of this feature to realize covert communication over long distances.

3. Watermarking

Watermarking is a process of embedding data in the digital signal [31,32]. It is used to verify the credibility of the content, copyright protection, or covert communication. In this section, the concept of watermarking is discussed, and introduces the novel concept of DCT watermarking in humpback whale song.

Generally, watermarking can be categorized by two broad categories termed as visible and invisible watermarking. Visible data embedded as watermarks is termed as visible watermarking and is usually used for copyright protection. For invisible watermarks, the embedded data are invisible and inaudible in the case of audio. These is used for covert communication as the information is hidden inside the carrier. The carrier signal is visible to the users, however, the data are concealed in such a way that their existence are unknown to intruders. It is decoded by a unique method known to the receiver. Several techniques of digital audio watermarking have been developed in the time and frequency domain [33]. Transform domain audio watermarking is more robust than the time domain due to the signal properties and auditory characteristics. The DCT based audio watermarking scheme is the most robust, imperceptive, and has high capacity [34–36].

3.1. Frame Structure

For biologically inspired covert communication, the complete signal should be identical to a natural sea sound including the synchronization signal. The frame structure for the novel concept is shown in Figure 3.

Figure 3. Frame structure of bionic mimicked signal.

The synchronization header consists of a humpback whale song segment with a checksum of bits. We added a checksum as it will verify the mimicked signal for the receiver. As there are plenty of humpback whales in the oceans and they emit sounds, the purpose of the checksum is to distinguish between the real humpback whale song and the mimicked signal for the receiver. The communication frame consists of the DCT watermarked mimicked signal.

3.2. Modulation

DCT audio watermarking is used to modulate covert information in the frequency domain in humpback whale song. DCT is similar to DFT, however, DCT has several benefits. It has a lower computational overhead and gives high capacity in low frequency components [34]. The embedded watermark is unnoticeable to human ears and vigorous against signal attacks. Mathematically, DCT can be written as [37]

$$X(k) = c(k)\sum_{i=0}^{N-1} f(x)\cos\left(\frac{\pi(2i+1)k}{2N}\right) \tag{1}$$

where, $c(k) = \begin{cases} \sqrt{\frac{1}{N}}, k = 0 \\ \sqrt{\frac{2}{N}}, k \neq 0 \end{cases}$ and $k = 0, 1, 2, 3, \ldots\ N - 1$.

The modulation process of watermarking secret information in bionic sound is presented in Figure 4. The high energy duration of a humpback whale's song is extracted and transformed to the frequency domain using DCT. Similarly, the information to be watermarked is also converted to the transform domain. The data are watermarked in the unique positions of bionic sound. These positions hold significant importance and will be needed for the demodulation of data at the receiver. These positions act as secret keys for covert communication. If the positions are known to the intruder, they might be able to decode the message if the eavesdropper recognizes it as a mimicked signal. However, the modulated signal looks identical to the humpback whale song and cannot be identified by the human auditory system (HAS) or through computer aided programs. The similarity between the real and mimicked signal will be discussed in detail in the next section.

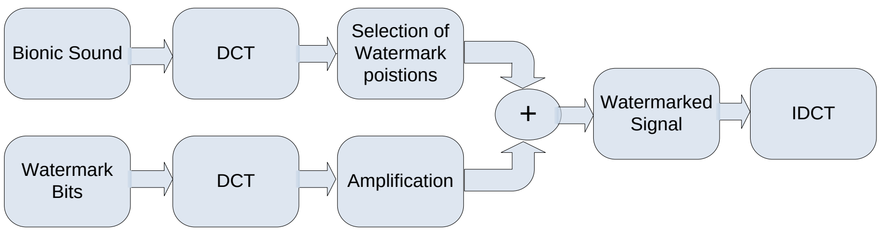


Figure 4. Modulation of data in bionic sound.

The bionic signal and watermark are summed up in the frequency domain by an amplification factor 'A'. 'A' plays a significant role; as 'A' is increased, the transmission distance is increased, thus degrading its imperceptibility with the original sound. The value of 'A' is adjusted considering the actual practical scenario. The mimicked signal with the watermarked covert data is converted back in the time domain and is transmitted in the underwater acoustic channel.

3.3. Demodulation

The watermarked bionic signal akin to the humpback whale song is recovered at the receiver using an energy detector. The demodulation procedure is demonstrated in Figure 5.

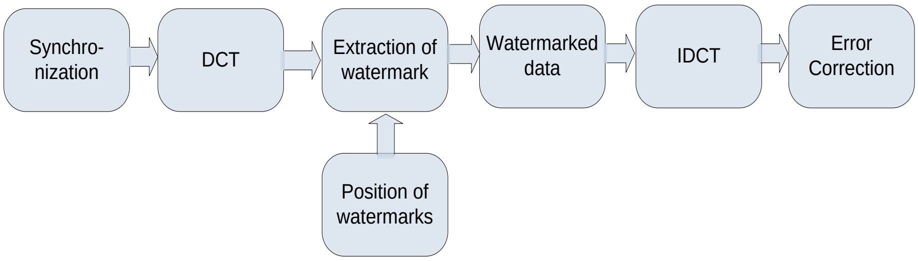


Figure 5. Demodulation of the mimicked signal.

The first step in extracting the watermark signal is synchronization. The synchronization header consisting of the song segment known to the receiver is correlated to identify it as the mimicked signal. It is further verified by the check sum of bits. The watermarked communication signal is extracted and converted to the transform domain using DCT. As discussed above, the positions of the watermarked bits act as secret keys to extract the information. These positions are known to the receiver or can be transmitted in a coded format. We assumed that these positions were known to the receiver for the sake of simplicity. The covert information is extracted at these positions by equating the amplification 'A', as per the modulation process. The data are recovered in the transform domain and converted to the time domain by taking the inverse DCT (IDCT). Mathematically, the IDCT can be equated as [38]

$$f(x) = \sum_{k=0}^{N-1} c(k)X(k)\cos\left(\frac{\pi(2i+1)k}{2N}\right) \tag{2}$$

where, $c(k) = \begin{cases} \sqrt{\frac{1}{N}}, k = 0 \\ \sqrt{\frac{2}{N}}, k \neq 0 \end{cases}$ and $i = 0, 1, 2, 3, \ldots N-1$.

Since the signal is degraded severely in the underwater acoustic channel due to noise, multipath arrivals, and absorption, the data are further processed through the equalization and error correction process. We validated our concept through simulation and an underwater tank test, which is elaborated in detail in Section 5.

3.4. Channel Estimation and Equalization

The underwater channel degrades the signal adversely due to multipath arrivals, the Doppler shift, absorption, and attenuation losses [39]. To overcome these effects, the channel is estimated and the errors are minimized through channel equalization. In this paper, we estimated the channel by the matching pursuit (MP) technique due to its robustness in changing the SNR and computational efficiency [40]. It can sequentially identify and estimate the channel tap coefficients. Let us assume that the multipath channel has additive white Gaussian noise (AWGN) with a variance σ^2. The received signal can be written as [41]

$$y(n) = \sum_{l=0}^{L-1} x(n-l)^{*}h(l) + v(n) \tag{3}$$

where $n = 0, 1, 2 \ldots, N-1$, $x(n)$ is the transmitted signal, $h(n)$ is the channel impulse response and $v(n)$ is the AWGN. Equation can be expanded as

$$\underbrace{\begin{bmatrix} y(0) \\ y(1) \\ \vdots \\ y(N-1) \end{bmatrix}}_{\mathbf{Y}} = \underbrace{\begin{bmatrix} x(0) & 0 & \cdots & 0 \\ x(1) & x(0) & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ x(N-1) & \cdots & \cdots & x(N-l) \end{bmatrix}}_{\mathbf{X}} X \underbrace{\begin{bmatrix} h(0) \\ h(1) \\ \vdots \\ h(N-1) \end{bmatrix}}_{\mathbf{h}} + v(n) \tag{4}$$

As almost all the components of channel tap are near to zero, the data is formed by accumulating the columns of $\mathbf{X}$. The residual vector $\mathbf{r}_{i-1}$ is the subtraction of vector $\mathbf{Y}$ with $\mathbf{X}$ in all $i-1$ repetitions, with $\mathbf{r}_0 = \mathbf{Y}$. At ith cycle, the column of $\mathbf{X}$ gives residual vector $\mathbf{r}_{i-1}$ has the maximum projection denoted as x_i which can be equated as [12]

$$x_i = \arg\max_{j \notin I_{i-1}} \frac{|\mathbf{X}_j^h \mathbf{r}_{i-1}|^2}{||\mathbf{X}_j||^2} \tag{5}$$

where $\mathbf{I}_i \triangleq \{x_1, x_2, x_3, \ldots, x_{i-1}\}$ is the index set of all previously selected columns. $\hat{h}_i$, member of $\mathbf{h}$ is calculated as

$$\hat{h}_i = \frac{\mathbf{X}_{S_i}^h \mathbf{r}_{i-1}}{||\mathbf{X}_{S_i}||^2} \tag{6}$$

The residual vector is computed as

$$\mathbf{r}_i = \mathbf{r}_{i-1} - \hat{h}_i \mathbf{X}_{S_i} \tag{7}$$

The aim of the MP algorithm is to estimate the effect of the multipath response in the underwater acoustic channel. The channel multipath response is required for equalization, which adds the distributed energy of the multipath to reduce errors. We equalized the errors using the virtual time reversal method (VTRM). The framework of the VTRM is shown in Figure 6. The communication system is mathematically defined as

$$r(t) = s(t) \otimes h(t) + n(t) \tag{8}$$

where $s(t)$, $r(t)$, $h(t)$ and $n(t)$ denotes the transmitted signal, received signal, impulse response and noise respectively. $\otimes$ represents the convolution operator. The estimated channel $h'(t)$ is reversed in time domain $h'(-t)$ and convolved with $r(t)$ to give the final virtual received signal.

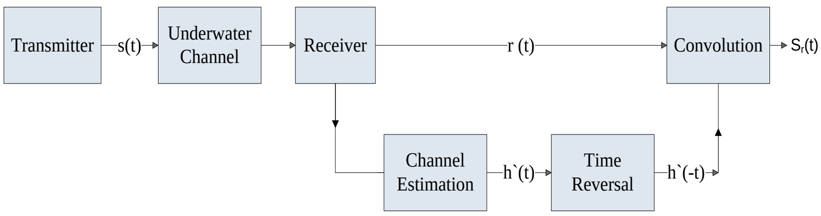


Figure 6. Framework of the virtual time reversal mirror method.

Therefore;

$$s_r(t) = r(t) \otimes h'(-t) \tag{9}$$

$$s_r(t) = [s(t) \otimes h(t) + n(t)] \otimes h'(-t) \tag{10}$$

$$s_r(t) = s(t) \otimes [h(t) \otimes h'(-t)] + [n(t) \otimes h'(-t)] \tag{11}$$

Here, $\hat{h(t)} = h(t) \otimes h'(-t)$ represents the VTRM channel. When $h'(t)$ approaches to the real channel $h(t)$, the multipath signals are overlapped which makes the signal energy vigorous. The central peak amplitude of $\hat{h(t)}$ is higher than the side lobes verifying the addition of signals. It also restrains inter symbol interference caused by multi path arrivals.

4. Imperceptibility and Camouflage Effect

The key aspect behind biologically inspired covert communication is the resemblance of man-made signals with the real natural vocals. In this section, the imperceptibility of the mimicked symmetrical signal and real ocean noise is calculated. The mimicked signal containing the watermark should be akin to the actual cetacean voice. If the intruder senses the mimicked communication signal, they should identify it as a natural sea noise due to its resemblance in structure, time duration, intensity, frequency, and modulation. The geographical location of a particular cetacean should also be considered and covert experiments should be performed in the same particular region where the specific cetacean exists.

There are several ways to check the imperceptibility and camouflage effect for audio signals. Usually, imperceptibility is measured through the human auditory system (HAS), time correlation, and comparing the frequency spectrum [33,36]. In this paper, we used time correlation to measure the imperceptibility between the real humpback whale song and the watermarked signal. Correlation is a matching process that shows how close two signal matches are to each other. The higher correlation value signifies a higher imperceptibility. Mathematically, correlation can be given as [42]

$$R_{xy}(\tau) = \int_{-\infty}^{+\infty} x(t)y(t+\tau)dt \quad for -\infty < \tau < +\infty \tag{12}$$

where $R_{xy}(\tau)$ is the correlation for all values of τ. $x(t)$ and $y(t)$ are the real humpback whale song and the mimicked watermark song, respectively. The signals are correlated in the time domain. The correlation peak and their sub band identify the similarity between the two signals. The peak value is divided by the summation of the sub bands. A larger value indicates a higher imperceptibility.

We compared the resemblance of the real and mimicked signal by varying the amplification factor 'A'. 'A' holds a significant importance for this biologically inspired covert communication because when this factor is increased, it increases the transmission distance in the underwater acoustic channel and degrades the similarity with the real humpback song. In Figure 7, the correlation peaks of the mimicked signal and the original humpback whale song were plotted with various values of 'A'. The correlation peak with less side lobes showed that the signal was more identical. As the side lobes increased, the resemblance with the real sound decreased. Figure 7 proves that the imperceptibility was degraded by increasing the value of the amplification factor 'A'.

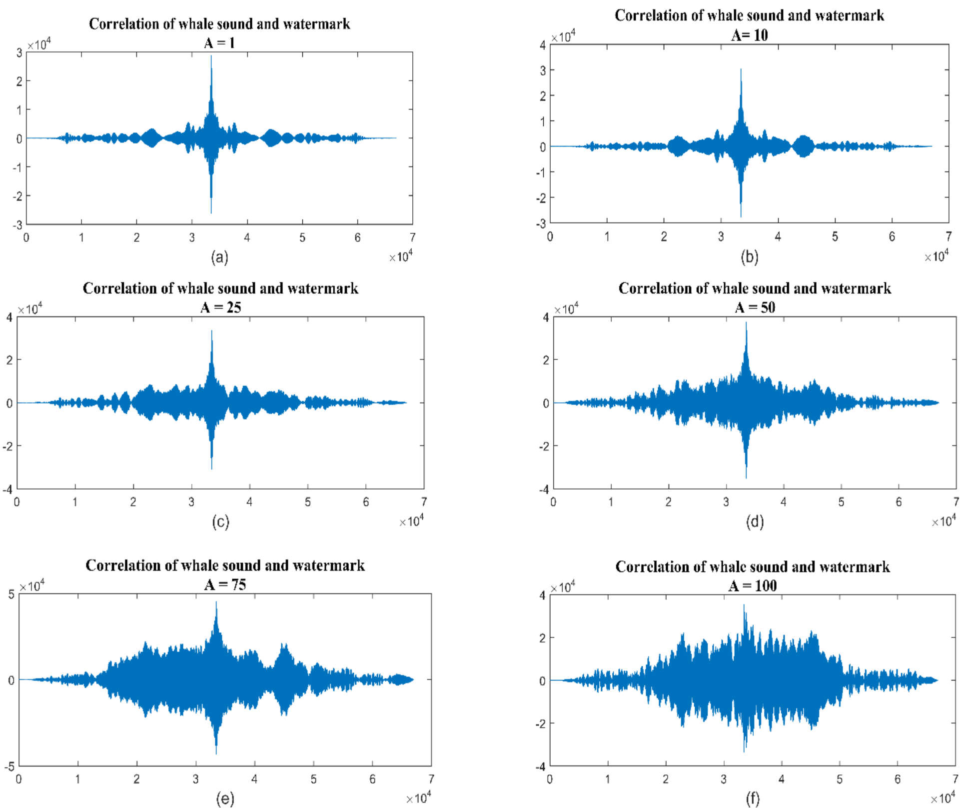


Figure 7. (**a–f**) Correlation of the real humpback whale song and the watermarked signal.

The value of 'A' can be adjusted with the real application scenario. For short distance communication, a lower value of 'A' should be selected to gain the benefit of high imperceptibility. For long distance communication, 'A' needs to be increased, but should not be increased above 25 as the imperceptibility severely degrades beyond this value, as shown in Figure 7d–f.

5. Experimental Validation

To verify the feasibility of the innovative idea, we conducted experiments in an underwater tank and simulations in MATLAB. For long range covert communication, we proved our concept through simulations using the bellhop acoustic model and experiments in an underwater tank provided the results for short range communication.

5.1. Simulation

A numerical simulation for long range covert communication was conducted in MATLAB. The sound speed profile in shown in Figure 8. First, we conducted the simulation in AWGN by varying amplification factor 'A'. The BER curve at the AWGN channel is presented in Figure 9 and shows that BER decreased with the increase of SNR. It can be clearly seen that above −5 dB SNR, the BER was less than 10^{-2}. By increasing factor 'A', the BER decreased effectively, however, it disturbed the similarity with the real humpback whale song as discussed in the previous section. The value of 'A' should be chosen through a tradeoff with BER and imperceptibility.

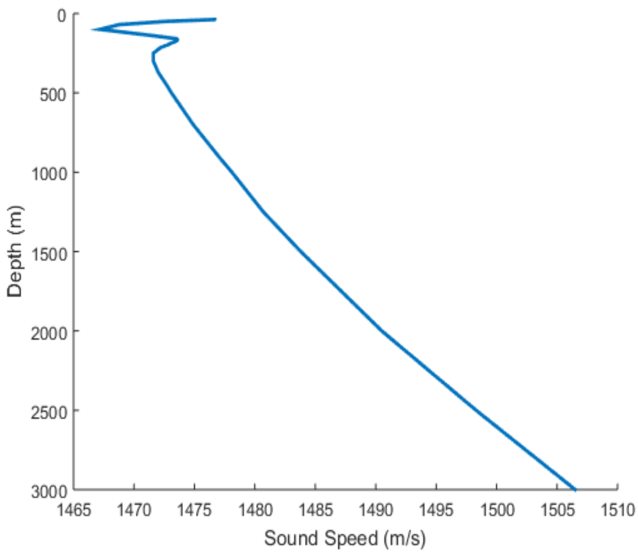


Figure 8. Sound speed profile of the underwater acoustic channel.

The simulation parameters for the multipath channel using the bellhop ray tracing model are listed in Table 1. We conducted simulations at various distances to obtain the maximum transmission distance with the lowest error. The BER curve for the multipath channel is displayed in Figure 10. It can be clearly seen that as the value of 'A' increased, the BER decreased. It can be concluded that by keeping the amplification factor between 15–25, we could attain covert communication up to 4 km with an acceptable BER of 10^{-2}. For short distance communication of around 2 km, the BER was extremely lower, regardless of the amplification factor 'A'. However, for long distance communication of 5–6 km, 'A' should be considered with a tradeoff of the BER and imperceptibility.

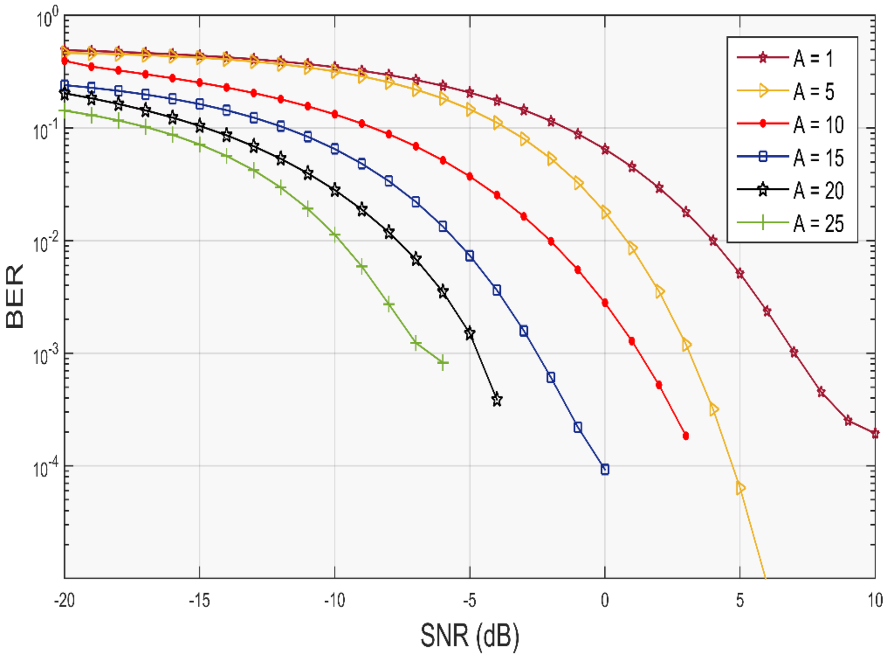


Figure 9. The BER curve at the AWGN channel.

Table 1. Technical parameters for the simulation.

S. No.	Parameters	Value
1	Sea Depth	3000 m
2	Depth of Transmitter	100 m
3	Depth of Receiver	150 m
4	Transmission Distance	1–6 km
5	Operating Frequency	48,000 Hz
6	Transmitter/Receiver quantity	01 each
7	Beam Angle	−30° to 30°

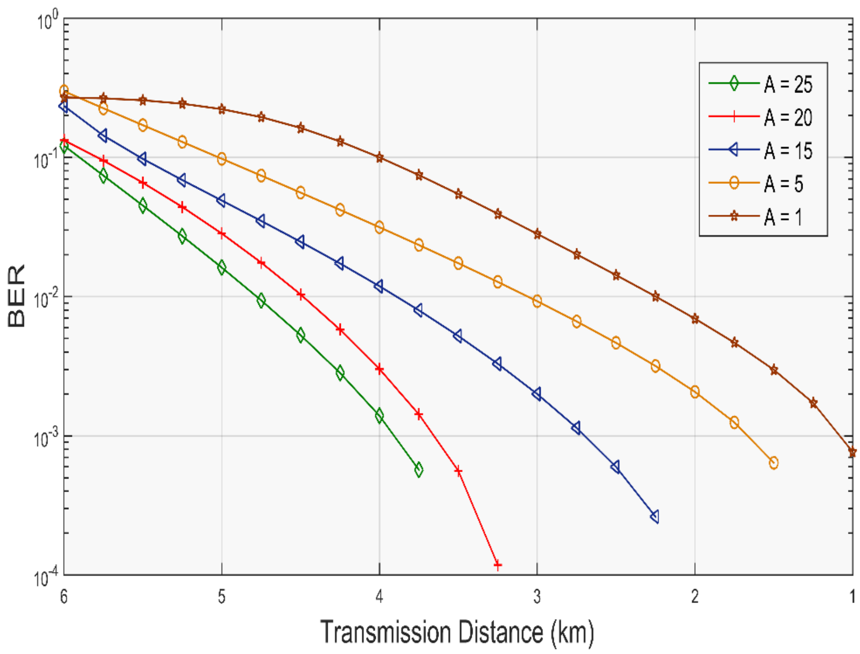
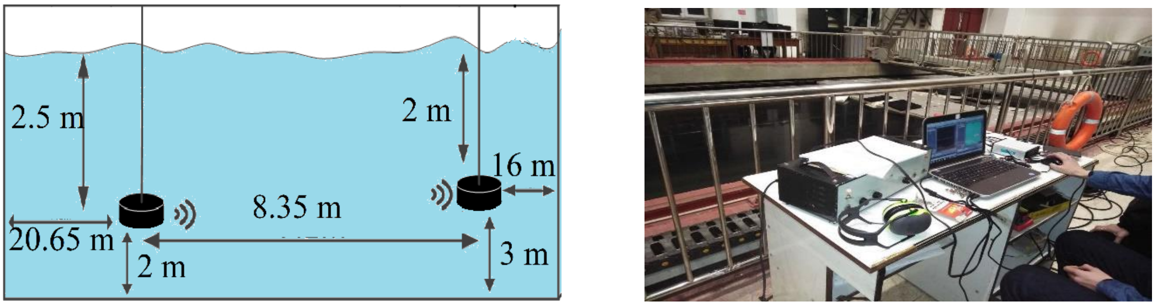


Figure 10. The BER curve at the multipath channel at various transmission distances.

5.2. Underwater Tank Experiment

To validate our innovative concept of DCT watermarking covert communication in the underwater multipath channel, pool experiments were conducted at Harbin Engineering University on 18 January, 2019. The length and breadth of the underwater tank was 45 meters and 6 meters, respectively, with the depth of 5 meters uniformly. The transmitter and receiver were placed at the depths of 2 meters and 2.5 meters, respectively. The distance between the transducers was 8.35 meters. A schematic and picture of the experimental setup is shown in Figure 11.



(**a**) (**b**)

Figure 11. Experimental setup. (**a**) Schematic, (**b**) Picture of conducting pool experiment.

The transducers were connected through a computer via a power amplifier, as shown in Figure 11b. The mimicked DCT watermarked acoustic signal was transmitted in the underwater tank through the computer software using a transducer. The communication signal created multiple arrivals at the receiver due to rebounds from the walls, top, and bottom surface of the underwater tank. Each path created a delayed arrival with a lower intensity. The intensity of the signal was reduced due to the absorption and attenuation of the signal. The communication signal was degraded rigorously due to severe multipath effects.

To overcome the effects of multipath effects, the MP algorithm and VTRM technique were used for channel estimation and equalization, respectively. The estimated channel of the underwater tank is shown in Figure 12. From the figure, we can see that there were plenty of multipath arrivals in the tank. Each energy was an arrival of the signal and due to the echoes from the borders and surface of the underwater tank. The high energy components were accumulated, while the low energy delayed arrivals were ignored for the sake of simplicity. The errors were equalized using the VTRM equalization technique as discussed in Section 3.4.

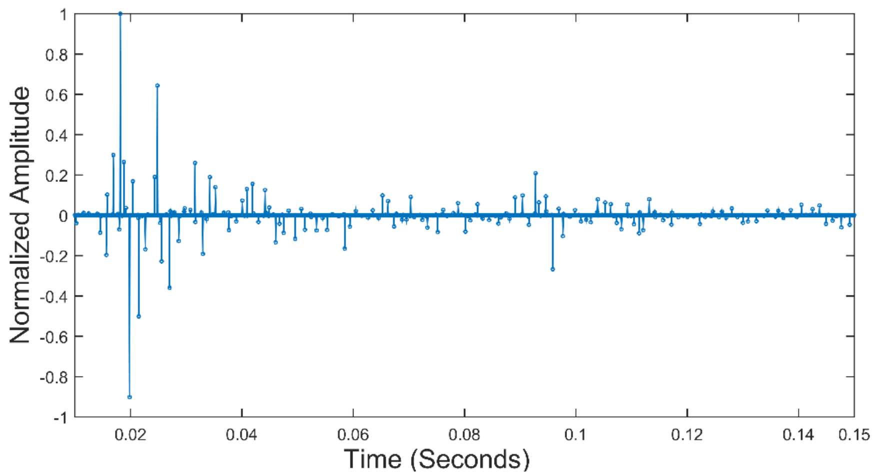


Figure 12. Estimated channel response of underwater tank by the MP algorithm.

Figure 13 displays the BER curve of the DCT watermarked mimicked signal in the underwater tank experiment without channel estimation and equalization. A 10^{-4} BER was achieved at 10 dB SNR when the amplification factor 'A' = 25. At the same SNR, considering an 'A' between 15–20, 10^{-2} BER was attained while the BER reached 10^{-1} by further decreasing the value of 'A'. The BER was increased drastically by reducing the value of 'A'. The errors were minimized by passing the signal from the estimated channel impulse response.

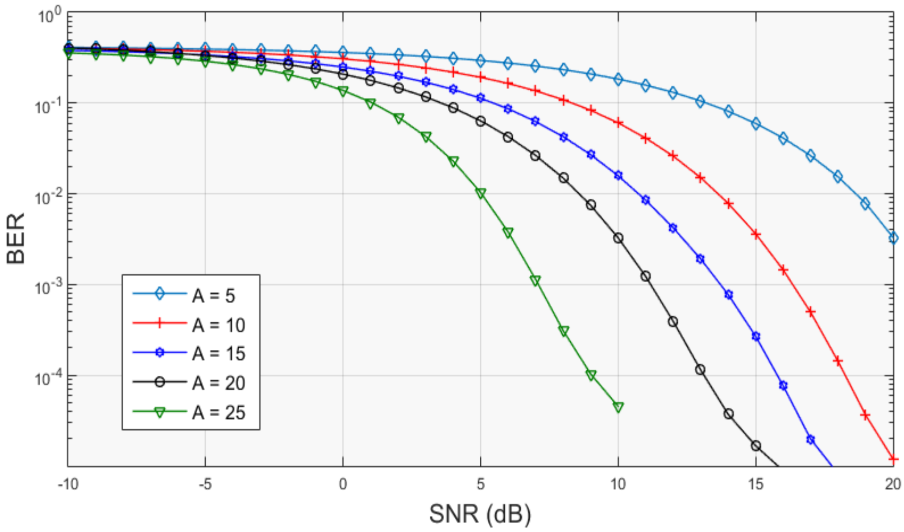


Figure 13. The BER curve without estimation in the underwater tank.

Figure 14 shows the BER curve of the DCT watermarked mimicked signal in the underwater tank experiment with channel estimation and equalization. It can clearly be seen from the figure that the BER was decreased by channel equalization. By comparing Figures 13 and 14, there was an evident −5 dB shift of the SNR by doing channel estimation, which means that this technique effectively reduced the errors. An almost negligible error was achieved above a 0 dB SNR after channel equalization, which proves that this innovative concept is feasible for covert underwater communication and is capable of efficiently transmitting the covert data at sea.

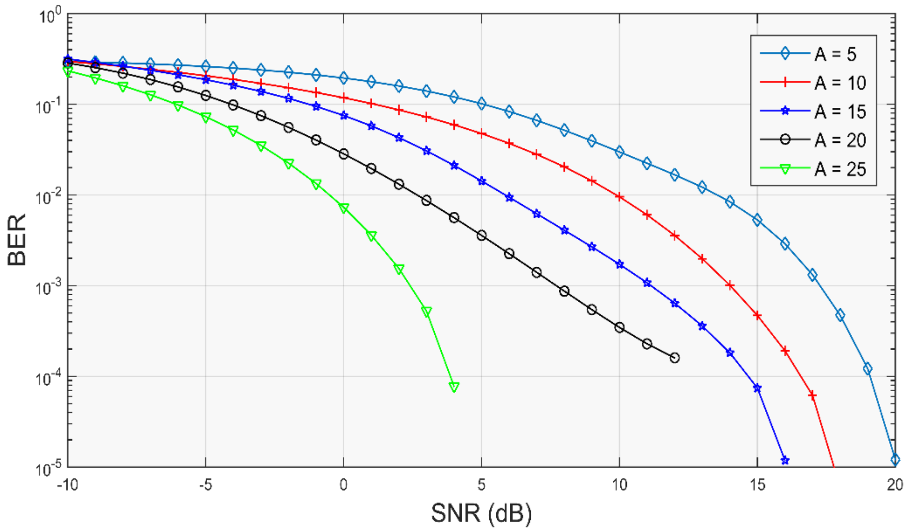


Figure 14. The BER curve with the MP estimation and VTRM equalization in the underwater tank.

6. Conclusions

An innovative idea of biologically inspired covert under water acoustic communication mimicking humpback whale song was presented in the article. The data were watermarked in the complex song using DCT. The mimicked signal looked symmetrical to the humpback whale song, which was verified by calculating the imperceptibility. The communication signal could be detected by an eavesdropper but was excluded from the process of recognition due to its similarity with the real humpback whale song. This gives perfect LPR constrained communication. The imitated signal is perceived by the intended receiver through a unique bionic synchronization signal with a checksum of bits. The innovative concept was verified through simulation and underwater tank experiments. Less than 10^{-2} BER was achieved with high imperceptibility at the transmission distance of 4 km. The communication distance could be further increased by degrading the imperceptibility. The underwater pool experiment was conducted to verify the effect of multipath induced in the mimicked signal. A 10^{-4} BER was achieved in the underwater tank experiment using the MP estimation and VTRM equalization technique. Our novel bionic covert communication technique was verified to be ideal for perfect furtive communication in the presence of an eavesdropper with better imperceptibility.

Future work includes a demonstration through lake and sea trails. The effect of the mimicked signal to marine life needs to be researched. The reaction of cetaceans or any possible harmful effects to the life of aquatic fauna needs to be addressed. The novel DCT watermarking techniques needs to be verified by other natural sea sounds, which will increase the locations for covert operations.

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