Real-Time Audio Steganography

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Abstract

Steganography is the practice of hiding information in plain sight; an uniformed observer is not even aware that a message is being sent. We present several methods for hiding information in audio, including echo hiding and spread spectrum with perceptual filtering. We also present a working communications system that implements these methods in real time. We analyze the bandwidth, robustness, and perceptibility of each method and present our findings.

System Description

- **SYNC:** Send sync signal. Encoder and decoder synchronize.
- **GO:** Once synchronized, the user tells the encoder to begin sending data. The encoder sends three repetitions of the GO signal to tell the decoder data is coming.
- **DATA:** The encoder is sends data and the decoder extracts transmitted data and tracks the data signal to stay synchronized.

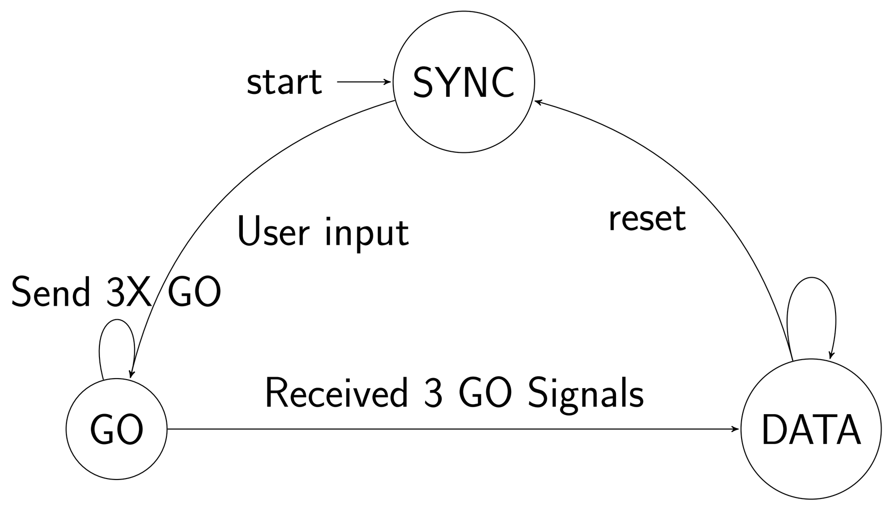


Figure: The state diagram for the encoder and decoder.

Synchronization and Tracking

To properly decode data, the decoder must be synchronized with the encoder. We synchronize by having the encoder send a known periodic signal, called SYNC. The decoder cross-correlates a reference of SYNC with the sampled signal. The figure below shows how the cross-correlation will have a peak that shows the offset between the reference and measured signals. Once this offset is found, the decoder shifts its measured signal to align perfectly with the reference SYNC.
The decoder also uses cross-correlation to continuously track the data signal.

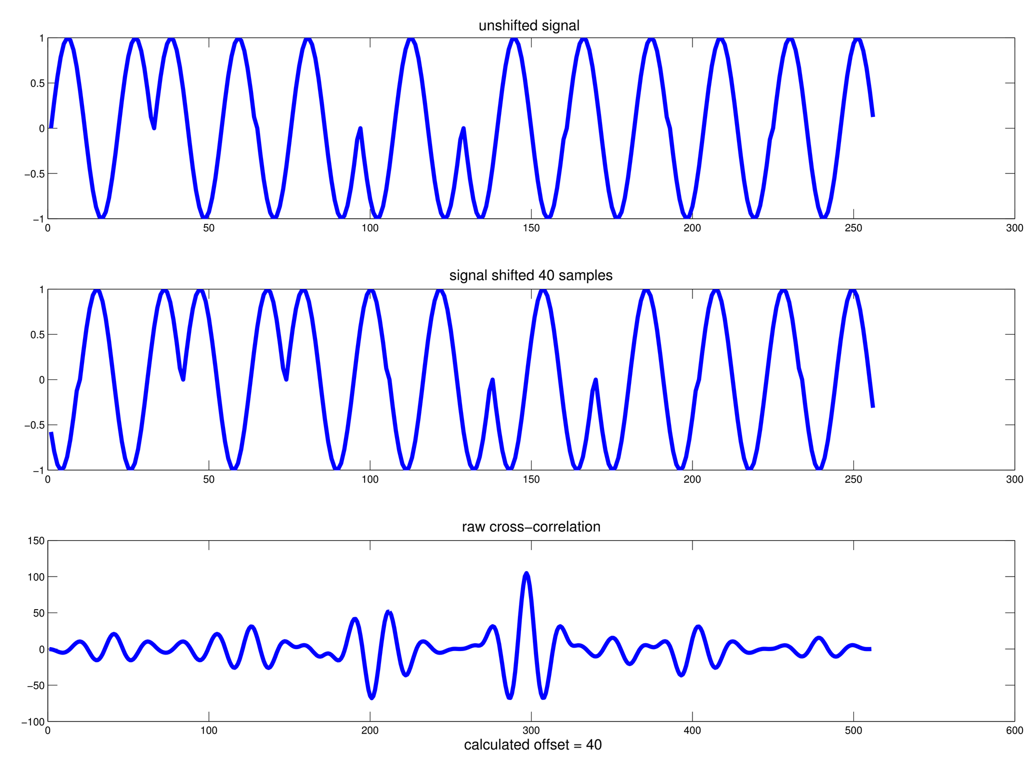


Figure: An example of a signal cross-correlated with a shifted version of itself. The maximum value of the cross-correlation shows how big the shift is.

Encoding Data

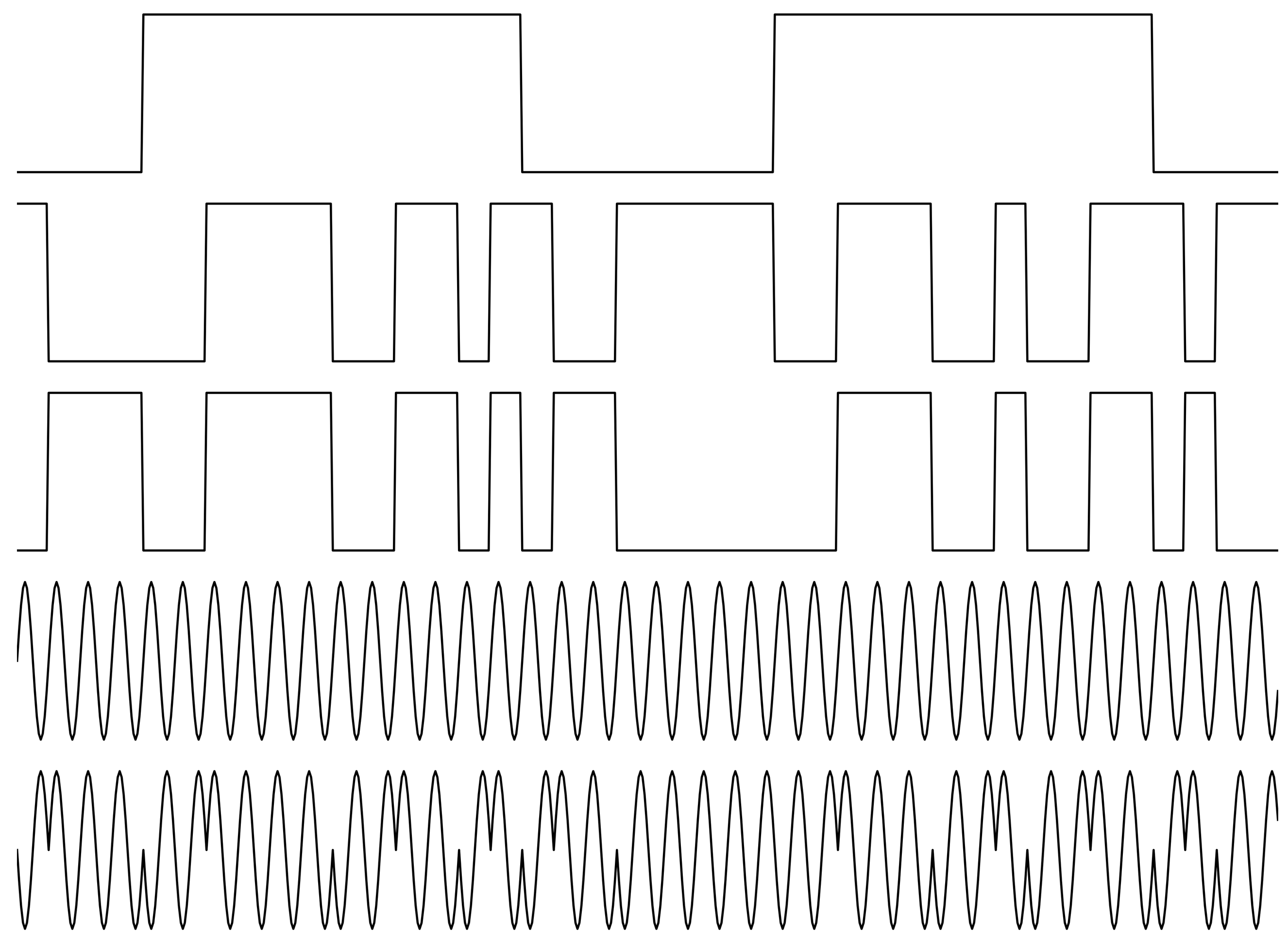


Figure: Diagram of various signals used to encode data using a spread spectrum technique.

In the plot above, the first signal shows data, the second signal is a higher bandwidth spreading sequence, and the third signal is the result of XOR'ing these signals. The fourth signal shows a sinusoidal carrier wave that is multiplied by the data and spreading sequence. This results in the bottom-most signal, which is added to the music signal.

Decoding

Let $[s_0\ s_1\ \cdots]$ be a spreading sequence and $\begin{bmatrix} r_0 \\ r_1 \\ \vdots \end{bmatrix}$ be received values. The decoder finds the inner product of these two sequences as

$$[s_0\ s_1\ \cdots]\begin{bmatrix} r_0 \\ r_1 \\ \vdots \end{bmatrix}$$

But we know that the received values are just the sum of the music and data:

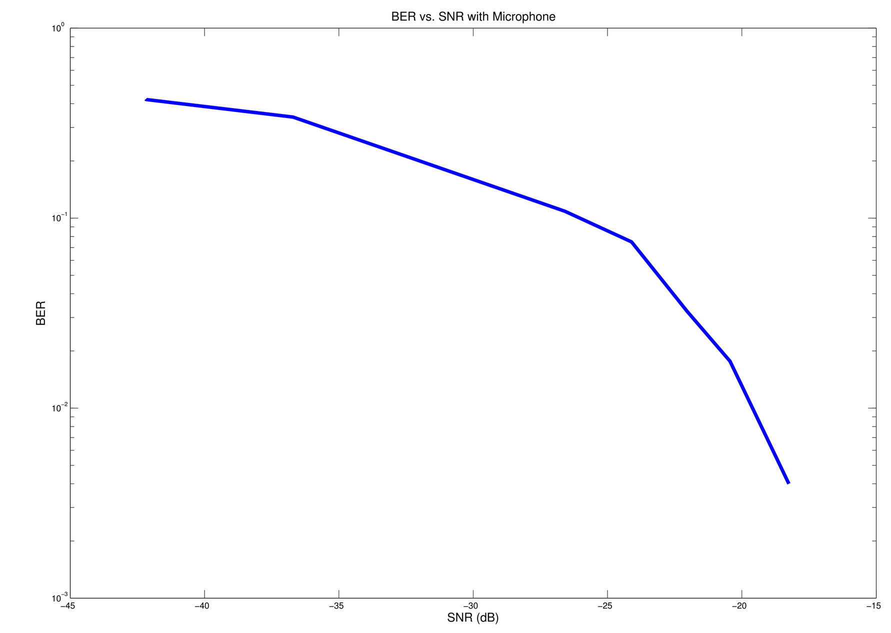
$$\begin{bmatrix} r_0 \\ r_1 \\ \vdots \end{bmatrix} = \begin{bmatrix} m_0 \\ m_1 \\ \vdots \end{bmatrix} + \begin{bmatrix} d_0 \\ d_1 \\ \vdots \end{bmatrix}$$

So

$$[s_0\ s_1\ \cdots]\begin{bmatrix} r_0 \\ r_1 \\ \vdots \end{bmatrix} = [s_0\ s_1\ \cdots]\begin{bmatrix} m_0 \\ m_1 \\ \vdots \end{bmatrix} + [s_0\ s_1\ \cdots]\begin{bmatrix} d_0 \\ d_1 \\ \vdots \end{bmatrix}$$

Because the music is uncorrelated with the spreading sequence, the first inner product has expected value zero. The inner product with data, given proper normalization, is ± 1, where 1 indictates a "1" bit and -1 indicates a "0" bit.

Error Analysis



Our team performed an analysis of bit error rate using a prototype system consisting of a microphone/pre-amp and speakers as the input and output to a transmitter/receiver pair. During the test, the music we used as input to the transmitter was the Beatle's "Ticket to Ride".

Prototype

Further Work

Our team has identified several shortcomings of our prototype–specifically, we envision a more robust communications system would consist of better sensors (microphone/pre-amp) and ADCs. Additionally, our current error correction techniques could be optimized for the particular acoustic channel we transmit data though. Finally, a perceptual filter could be implemented to further reduce the noticibility of the hidden data; however, such a filter may require a more powerful DSP chip.

References

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