Sampling, Convolution, and FIR Filtering applied to Audio Signals and Edge Detection in UPC Symbols

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BACKGROUND

- A Finite Impulse Response (FIR) filter can convert an input signal x[n] to an output signal y[n] by means of a weighted summation
- First Difference Filter

$$B_k = [\,1, -1]$$

- Applications addressed in this study:
  - Edge Detection
  - Echo
  - Cascading Two Systems
  - Bar code detection and decoding
- All signals used in study are:
  - Time-Invariant
  - Linear
  - Causal

OBJECTIVE

To learn how to implement FIR filters and the study the response of FIR filters to various signals, including images and speech.

METHODS

- **Echo: FIR filters can produce echoes and reverberations.**

Weighted summation $\rightarrow y[n] = \sum_{k=0}^{M} b_k x[n-k]$

FIR echo filter $\rightarrow y[n] = x[n] + rx[n-p]$

- **Cascading Two Systems:**

$$FIR\ Filter\ 1 \rightarrow w[n] = x[n] - qx[n-1]$$

$$FIR\ Filter\ 2 \rightarrow y[n] = \sum_{k=0}^{M} r^l w[n-l]$$

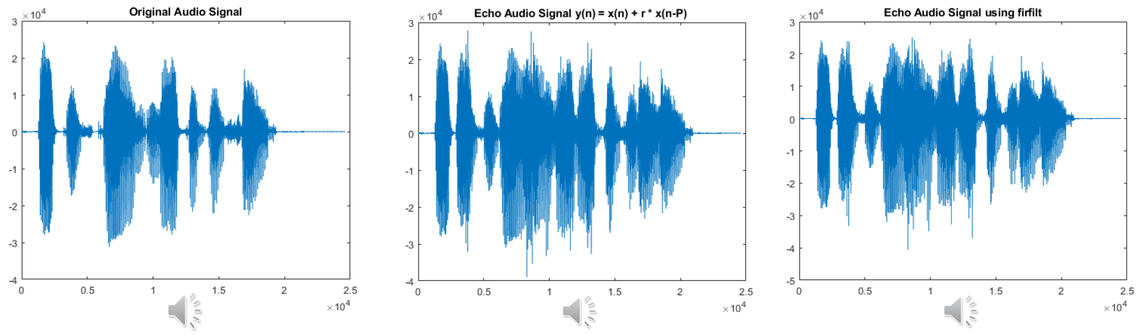
- **Edge Detection for a UPC symbol:**
  - Each digit has a sequence of 4 bars with 4 widths:
    - 0 = 3-2-1-1 5 = 1-2-3-1
    - 1 = 2-2-2-1 6 = 1-1-1-4
  - 7 basic bar widths
  - 59 total bars
  - Invalid patterns return a (-1) error

RESULTS

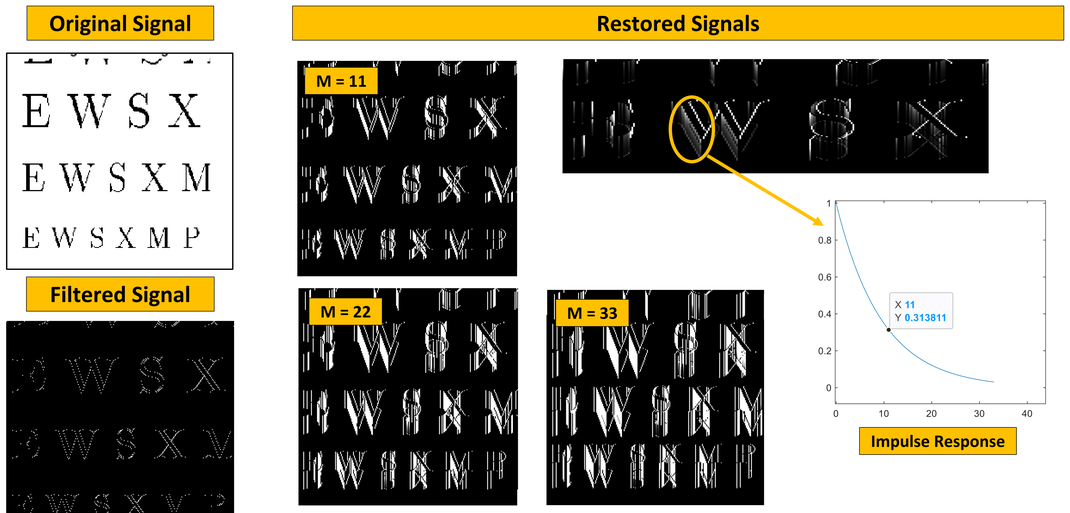
Echo Filter

Sampling Frequency Fs = 8 kHz
Time delay = 0.2 s(p).

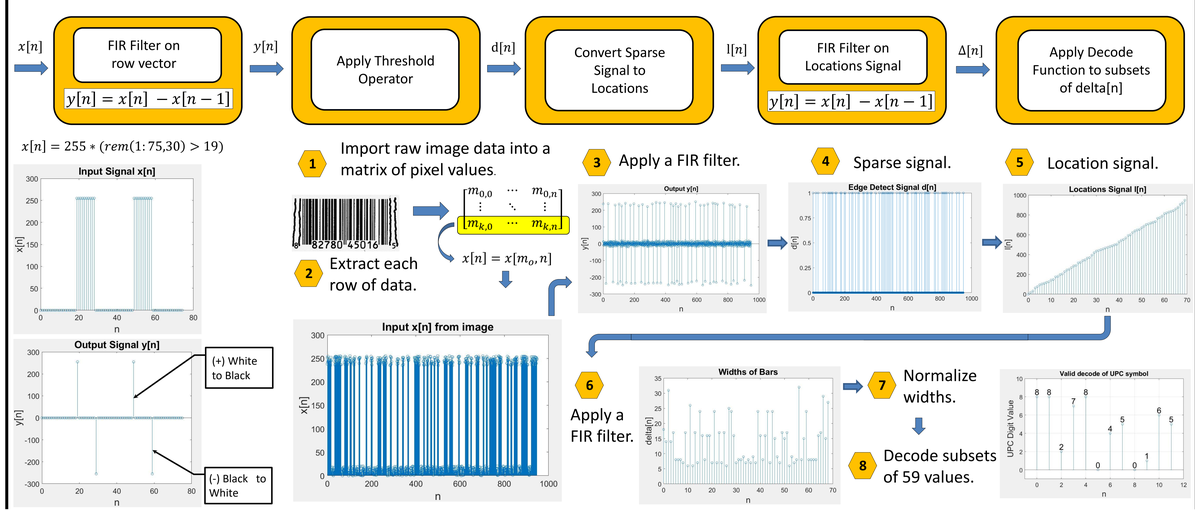
Sample delay = 1/Fs = 125 us.
Echo strength 90% (r).



Cascading Two Systems



UPC Bar Code Detection and Decoding



DISCUSSION

- The sampling frequency needs to be known to integrate an echo to satisfy the Nyquist frequency
- An echo's scaling and delay are needed to define the filter's coefficients
- As M increases, the length of the ghost increases
- As R decreases, the values on the grayscale exponentially drop off
- Defining the range of your gray scale impacts the visualization of the filter's effects
- The 1-D FIR filter readily decoded a standard image test case.
- A more robust application algorithm of the basic tools could extend the application capability to read a skewed image, and possibly enable decoding of a damaged bar code.

CONCLUSION

- For the human ear to detect an echo, a time delay of approximately 0.015 seconds is required. Any delay lower than 15 (ms) is going to result in reverberations not easy to perceive.
- FIR filters are often used to produce any repeated effects in music
- An exponential decay impulse response produces a ghost effect in the resultant image
- Any ghost effects are elongated by increasing the upper limit of your convolution
- FIR Filters can be used produce text effects displayed in Microsoft WORD and other platforms
- 2D barcodes such as QR Code, Datamatrix, MaxiCode, PDF-417 evolved from the UPC 1D barcode. A major advantage of the 2D barcode is that they are damage resistant due to the use of Reed-Solomon error correction.
- Many additional edge detection algorithms exist. Several common ones are: Sobel, Canny Prewitt, Roberts, and fuzzy logic methods. Edge detection is used in medical imaging, fingerprint identification, satellite image processing, and machine vision.

REFERENCES

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[2] McClellan, Schafer, and Yoder, *Signal Processing First*. Upper Saddle River, NJ, USA: Prentice Hall, Lab P-9: Sampling, Convolution, and FIR Filtering, pp. 1-11.

[3] McClellan, Schafer, and Yoder, *Signal Processing First*. Upper Saddle River, NJ, USA: Prentice Hall, Lab P-10: Edge Detection in Images: UPC Decoding, pp. 1-8.