AUTOMATIC MODULATION CLASSIFICATION FOR THE ADAPTIVE DEMODULATION OF RADIO SIGNALS

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OVERVIEW

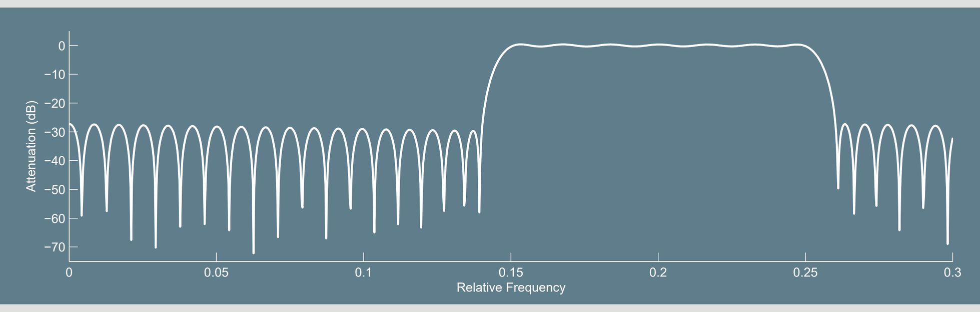
Automatic Modulation Classification involves the identification of a modulation scheme without any prior information. The system developed as part of this project performs automatic modulation classification by extracting features from the time-domain and frequency-domain representations of an intercepted signal.

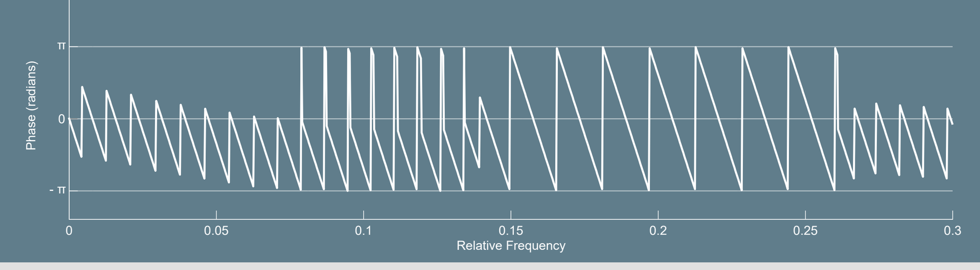
The features extracted from a signal in this way are processed by a binary tree classifier.Zhu and Nandi propose a tree structure based purely upon the knowledge of how the features have been derived. The performance of this classifier is measured against that of a classifier with a structure derived from simulated experimental data.

DIGITAL SIGNAL PROCESSING FOR FEATURE EXTRACTION

Filtering

The intercepted signal to be classified must be isolated from the rest of the spectrum in order to prevent pollution of the features by other signals. This is done using a 128-tap FIR band-pass filter. This filter, generated by a Marks-McClellan algorithm, is dynamically changed by the user when investigating the spectrum, the following two graphs illustrate the properties of this filter at one point in time.



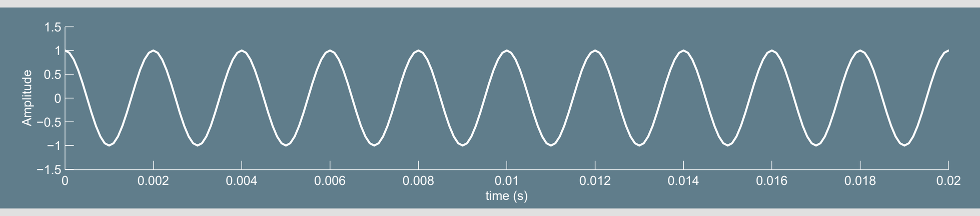


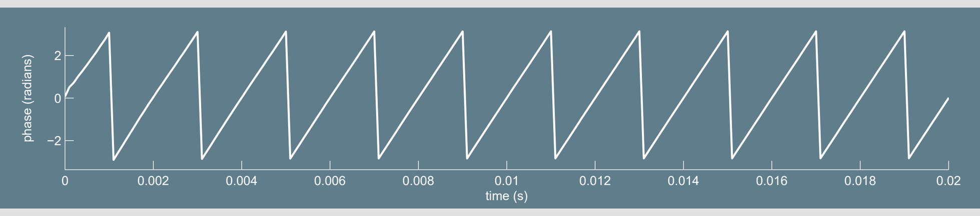
Phase Unwrapping for Instantaneous-Phase and -Frequency

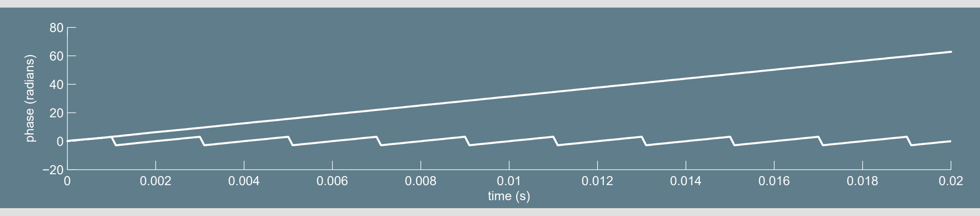
The instantaneous phase of the real-valued signal intercepted by the USRP is obtained by performing an FFT on the data, removing the negative frequency components and then performing an IFFT. The instantaneous phase is presented as the angle of the resulting complex number sequence.

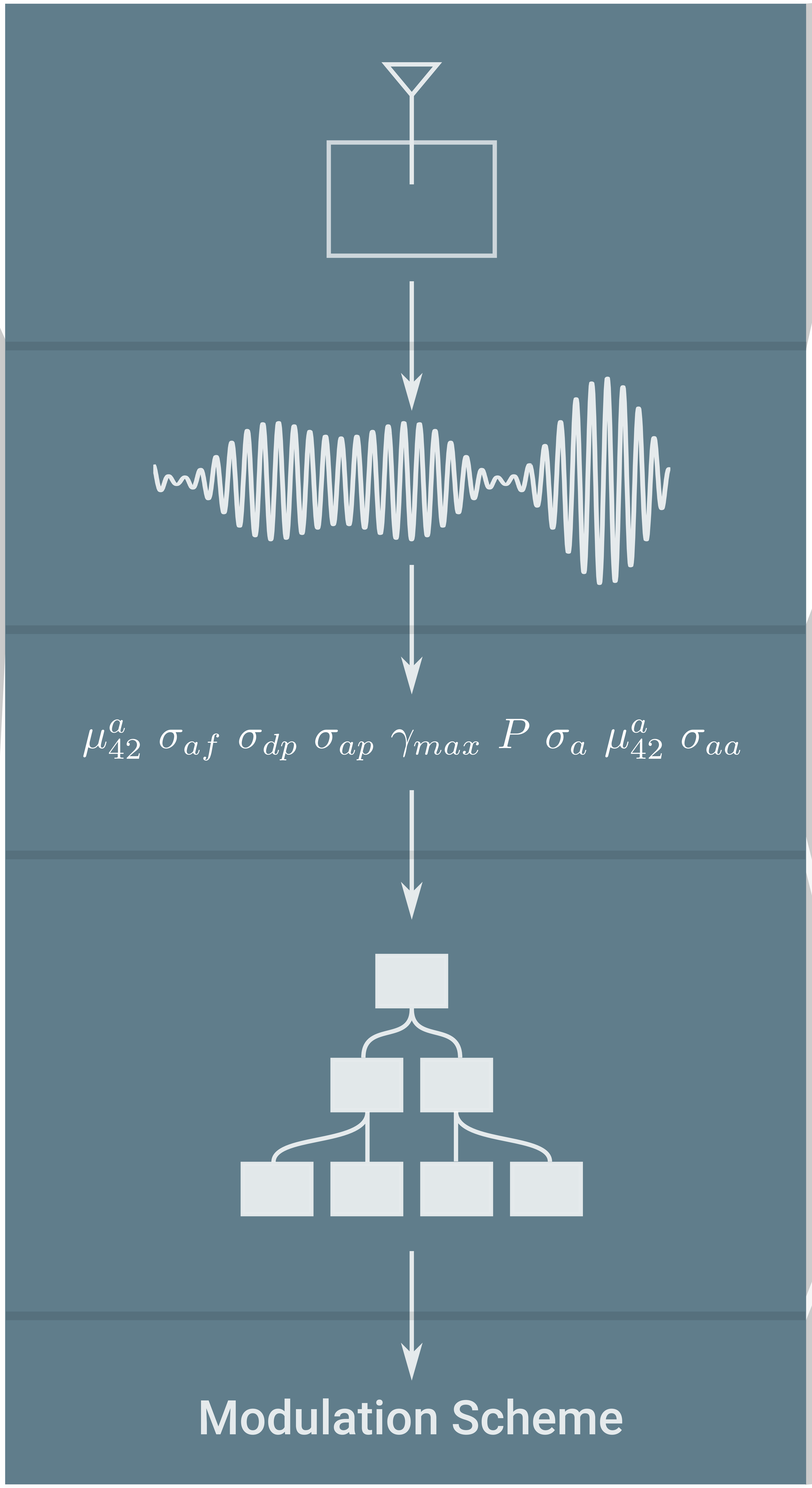
The instantaneous phase is jagged; appearing in a centered modulo-2pi form. This is remedied by phase unwrapping, where changes larger than pi is corrected by adding 2pi to all the following samples. This process also corrects the jaggedness of the FIR-filter in it's pass-band.

The following three graphs illustrate the process of phase-unwrapping.









USRP N210 0-30MHz

Universal Software Radio Peripheral.
A Software defined radio developed by Ettus Research.
Used here for receiving radio-frequency signals

LIBRARIES

In order to complete a project of this scale in six weeks we resorted to using various libraries to implement routines that are beyond the scope of the project. These libraries, and what they are used for are listed below.

Uhd
The USRP Hardware Driver. provides a C++ API for communicating with a USRP
Fftw3
A very efficient C-library used for performing FFT's and IFFT's
Liquid Dsp
A C-library used for miscellaneous DSP tasks, such as performing modulation and demodulation and generating filters
Boost
Handles miscellaneous tasks such as smart-pointers, mutexes, threading and timing.
Port Audio 2.0
C-Library used to play audio
OpenCV
A C++ computer vision library which offers algorithms for machine learning

FEATURES

Nine features are used to classify signal modulation schemes. They are divided into two broad categories (spectral and statistical) and are enumerated below, along with their formulas.

$$\mu_{42}^f = \frac{E(f_N^4[n])}{(E(f_N^2[n]))^2}$$

$$\sigma_{ap} = \sqrt{\frac{1}{N_c}(\sum_n \Phi_{NL}^2[n]) - (\frac{1}{N_c}\sum_n |\Phi_{NL}[n]|)^2}$$

$$\mu_{42}^a = \frac{E(A_{cn}^4[n])}{(E(A_{cn}^2[n]))^2}$$

$$\gamma_{max} = max|DFT(A_{cn}|^2/N$$

$$\sigma_a = \sqrt{\frac{1}{N_c}(\sum_n a_{cn}^2[n]) - (\frac{1}{N_c}\sum_n a_{cn}[n])^2}$$

$$P = \frac{P_L - P_U}{P_L + P_U}$$

$$\sigma_{af} = \sqrt{\frac{1}{N_c}(\sum_n F_N^2[n]) - (\frac{1}{N_c}\sum_n |F_N[n]|)^2}$$

$$\sigma_{aa} = \sqrt{\frac{1}{N_c}(\sum_n a_{cn}^2[n]) - (\frac{1}{N_c}\sum_n |a_{cn}[n]|)^2}$$

$$\sigma_{dp} = \sqrt{\frac{1}{N_c}(\sum_n \Phi_{NL}^2[n]) - (\frac{1}{N_c}\sum_n \Phi_{NL}[n])^2}$$

CLASSIFIERS

Two different tree classifiers are implemented so that their performance may be compared. The first is taken from Zhu & Nandi's "Automatic Modulation Recognition of Communication Signals". It's structure is based upon the knowledge of what the features are and the node-thresholds are computed so as to be optimal. The second is generated using OpenCV's decision tree framework. Its structure and thresholds are generated based entirely on the training-data it is given.

MODULATION SCHEMES

The system is capable of classifying 10 modulation types. These are listed below.

- AM-DSB-FC
- AM-DSB-SC
- AM-USB
- AM-LSB
- FM
- M-PSK
- 2-PSK
- M-ASK
- 2-ASK
- M-QAM