COGNITIVE RADIO DEVELOPMENT THROUGH THE IMPLEMENTATION OF SOFTWARE DEFINED RADIO

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ABSTRACT

The main objectives of the research were twofold: to develop a test-platform for testing Software Defined Radio (SDR) implementations and to assess a suitable method of automatic recognition of radio signal modulation schemes for a Cognitive Radio. A TMS320c6713 DSP kit was used for the SDR front-end to evaluate the feasibility of the SDR implementation at a very low frequency range around 8 kHz. This test-platform encapsulated all the ADC and de-modulating functionality on a software defined platform**.** This was interfaced with MATLAB through Code Composer Studio using the RTDX host library provided. An envelope de-modulation scheme was successfully implemented. The automatic modulation recognition scheme was implemented with a mixed set of techniques: Neural Networks, Statistical Signal Processing and some DSP techniques. The Statistical Signal Processing part extracted signal envelope and phase information to reduce the complexity of the Neural Network and improved on the overall approach on classification. A Learning Vector Quantization (LVQ) network with 5 statistical parameters as inputs and six outputs for the different signals classified was trained using the Levenberg-Marquedt algorithm with a pre-generated test-data set. The MATLAB Numerical Processing Platform was used to generate and evaluate the Automatic Modulation Recognition Scheme and was able to partition the vector-space to the required 6 dimensions with a fair degree of accuracy but varied for the different modulation schemes employed.

INTRODUCTION

SDR Introduction

The SDR is a general-purpose integrated software and hardware platform used to realize platform independence in radio communications. It has such potentials as being the basis for the Cognitive Radio (CR) and Base Transceiver Station (BTS) in 3rd and 4th generation mobile communication architectures. It was first started as a pilot project by the U.S. DoD to enable radio communications for 2 MHz to 2 GHz range, and operate with ground force radios (frequency-agile VHF, FM, and SINCGARS), Air Force radios (VHF AM), Naval Radios (VHF AM and HF SSB tele-printers) and satellites (microwave QAM).

The main focus of the SDR concept is to transfer as much of RF signals as possible into the digital domain so that the RF activities, traditionally carried out in analog and non-reconfigurable digital circuits, can be done in reconfigurable digital circuits. Since the capabilities of reconfigurable digital technology are improving on a regular basis, the interface between RF and digital signals has become more critical. Figure 01 illustrates the receiver side of ideal SDR concept. Successfully implemented, this can deliver an obsolescence-proof radio product which can support many existing and future air-interfaces and modulation formats.

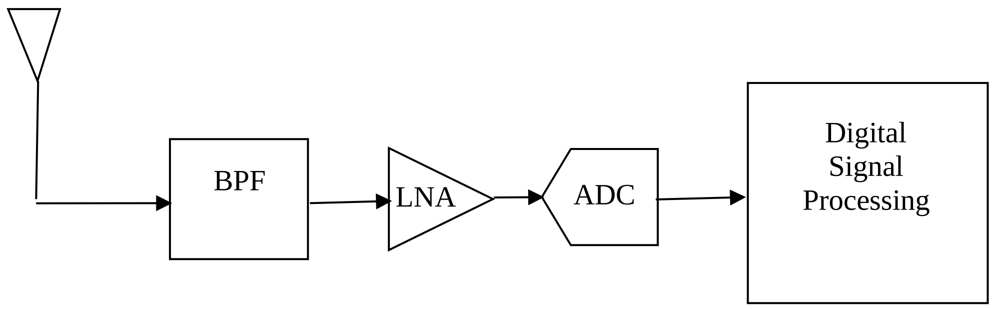

Figure 01: Ideal SDR Receiver

The ideal SDR architecture is simple but it is more difficult to realize, mainly due to the necessity of handling large frequency bandwidths and the rapid data processing. Consequently, the antennas must be wide band and the use of multiple antennas is needed. The filters, low noise amplifiers, analog to digital converters, digital to analog converters should also support the same analog bandwidths. In order to handle the digital data corresponding to a large bandwidth, data processing must be high speed. As a result of that the power consumption also increases rapidly. [7]

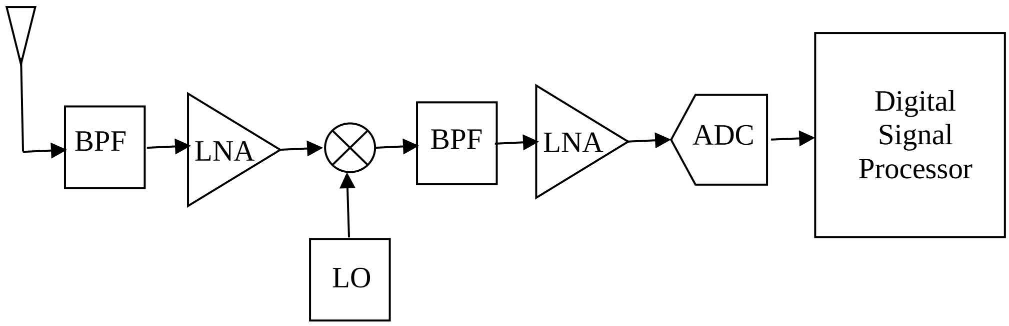

Figure 02: Feasible SDR Receiver

Specifications for SDR Implementation

The practical implementation specification of an SDR largely depends on the application. If it is necessary to implement a cognitive radio network as a data communication system, depending on the number of nodes needed and the data bandwidths of the nodes, along with other requirements would collectively decide what frequency range to be handled, the noise performances of individual and the overall system, etc.

With the objective of providing a platform for cognitive radio development, it was not necessary for us to deal with a large frequency band because the intended cognitive operations to be tested did not demand a wide band width but the handling of more variant modulation/ demodulation schemes. For the implementation of the neural network and for training it the base band signals were used.

Therefore, not much effort was taken for expanding the RF front end, but the base band signals were manipulated using the TMS320C6713 DSPKit. The transmission and the reception of radio signals were done at a carrier frequency of 100MHz.

Additional hardware was used to provide the DSP kit with the required base band signals needed in cognitive radio development. The C6713 DSK is a low-cost standalone development platform that enables users to evaluate and develop applications for the TI C67xx DSP family. The DSK also serves as a hardware reference design for the TMS320C6713 DSP. The DSP interfaces to analog audio signals through an on-board AIC23 codec.

The basic implementation of an envelope-detector was done as seen in the following illustration using the DSP Kit and Matlab.

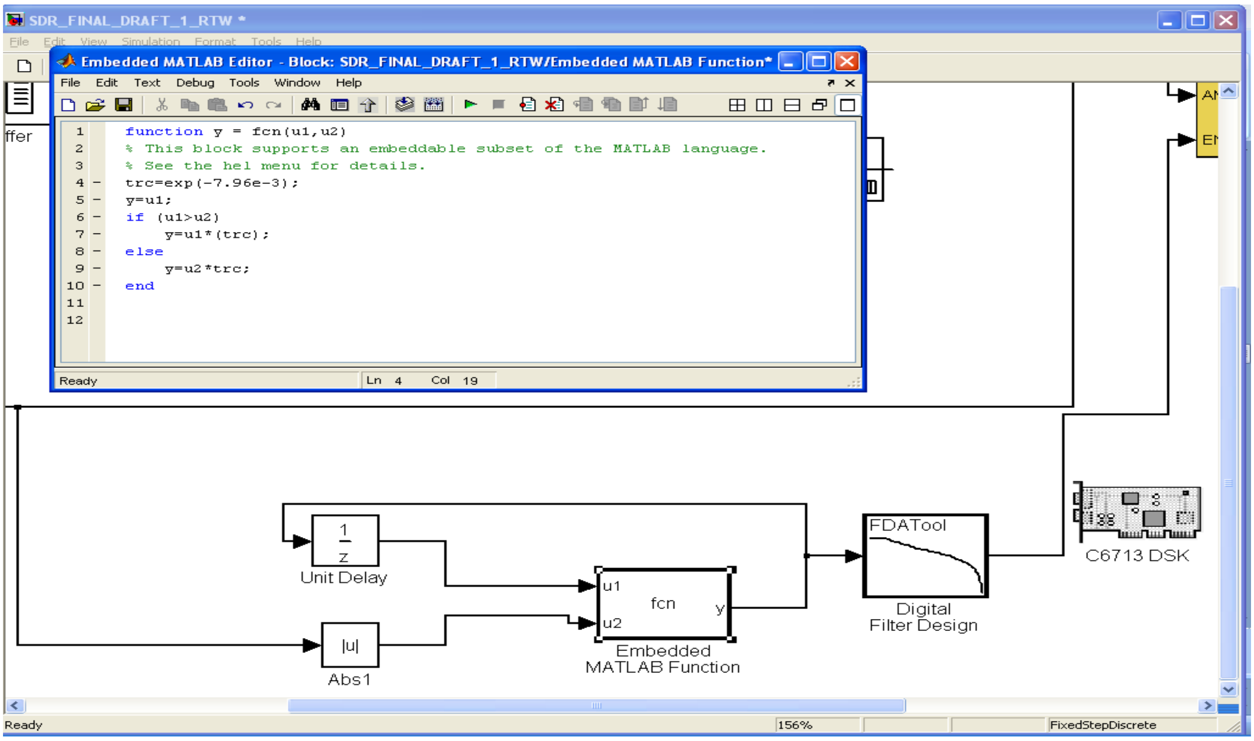

Figure 03: Envelope-Detector

Cognitive Radio Introduction

The Cognitive Radio (CR) is an intelligent node in a radio network which can use many techniques to efficiently manage the radio spectrum such as dynamic bandwidth allocation, dynamic channel allocation and spectrum awareness. A CR might use one or any combination of these techniques and many more which are still under development in the global arena.

The intelligence of CR's is a different form from other general artificial intelligences like AI-based services like intelligent agents, computer speech, and computer vision in degree of focus. Consider,

> '…CRs focus on very narrow tasks. For CRs, the task is to adapt radio-enabled information services to the specific needs of a specific user.' [1]

CR's allow switching between different modulation schemes and different protocols by employing its SDR capabilities to account for the local radio environment. Almost all CR's implemented so far are **Spectrum Sensing Cognitive Radios [2].** Since, it is not practical to cope with sensing all the parameters associated with the network, **Fully-Fledged Cognitive Radios** are still in their infancy.

Therefore, the main part of the CR implementation process was the development of an **Automatic Modulation Schemes Detection Method**.

Software Components

The software modules employed for this purpose were:

Matlab

- Filter Design Toolbox
- DSP Blockset

- Simulink
- TI Target for c6000
- Communications Blockset
- Real-Time Workshop Embedded Coder

Code Composer Studio
- RTDX

RTDX permits developers to transmit and receive data between a HOST and a target DSP without stopping their applications and to view live or saved data via an easy-to-use Object Linking and Embedding (OLE) Application Program Interface (API).

APPROACH

Automatic Modulation Schemes Recognition

A Learning Vector Quantization (LVQ) network with 5 statistical parameters as inputs and six outputs for the different signals classified was trained using the Levenberg-Marquedt algorithm with a pre-generated test-data set. This approach was selected based on the following observations:

1. Even though the FFT-Analysis method was seen to give appreciable results for some modulation schemes, at least a 512 point FFT would have to be used and this would have made using a neural network based approach very time and resource consuming.

2. The Time-Domain signals could have been directly fed into the neural network: However, training this network is especially time consuming as we have to use a fair amount of signal sampled points even for the time domain case. However, training this network with, say, 1000 data points would at least require 2000 sample vectors in the first case and several more passes to train for the training process to achieve the required goal or gradient. This is not easy, as we also have to use one or more hidden layers for which the number of neurons can be chosen quite arbitrarily, but as a measure of thumb, is usually taken as half of the amount of neurons in the input layer for a network with just 1 hidden layer. As can be seen, this amounts to huge number of input and layer weights, not to mention biases that have to be updated to reach the required goal. The best Pentium processors require a huge amount of time for this purpose. Furthermore, the Levenberg-Marquardt algorithm (which is used to train the neural net) sometimes runs out of memory and halts the training process which complicates matters further.

3. Therefore, to reduce the complexity of the Neural Network (NN), we used statistical parameters obtained from the waveforms themselves as inputs to the NN.

The training of the net was by using the Levenberg-Marquardt algorithm. This algorithm is particularly suited for this case as it has a very efficient MATLAB implementation, because the solution of the matrix equation is a built-in function, so its attributes become even more pronounced in a MATLAB setting. Also, this algorithm is known to be the fastest for moderate sized neural nets (of up to several hundred weights).

- The modulation schemes employed were AM, FM, BPSK, BASK, ASK4 and ASK8.
- The statistical parameters used were
  - Standard Deviation (SD) of Signal Amplitude
  - SD of Signal Envelope
  - SD of change of phase
  - SD of the change in phase and
  - SD of the phase.
- Sampling Frequency was 80 Hz and 100 cycles were used as the time-window for the calculation of the Standard Deviations.
- The LVQ NN with 5 inputs and 6 outputs had 1 hidden layer with 20 neurons.

The result was fairly well partitioned feature space for the modulation schemes employed.

CONCLUSION

The first conclusion that can be reached is that the basic functionalities of both the SDR and CR were successfully implemented in our project. It was able to perform the basic SDR functionality of software-based modulation and demodulation albeit with a super-heterodyne type front-end. It was also able to intelligently recognize modulation types via the NN approach. This is a basic requirement of a CR which is to be aware of the radio spectrum. However, the task of running both the SDR and the CR in real-time with Automatic Modulation Schemes Recognition capabilities will be a challenge as all processing and resource requirements will have to be met – we were not able to do this task of integration in real-time.

The basic idea of using reconfigurable hardware for the SDR was achieved by using the TMS320c6713 DSP kit. It is able to be re-programmed on a very short time basis, but it is not done on the fly – or in real time. Typically, when using the Matlab – CCS interface to program the device, it takes around 20 – 30 s depending on the type and processing power of the PC platform used for this purpose. Our compiling was done on an IBM Thinkpad with 1.70 GHz processor with a RAM of 504 MB and 599 MHz bus speed. Of course, we did not take into account the background windows processes that were running and shutting down all, but the most critical processes might probably be associated with a significant reduction of compiling time.

The coding time was reduced to a minimum by using the Matlab 'TI Target for c6000' toolbox. This was a handy toolbox, as there was almost no coding performed for that part. It offered a comprehensive set of tools for handling the DSP functions and peripheral functionalities associated with the TMS320c6713 DSP kit. The RTDX (Real Time Data Transfer) tool offered by CCS was used successfully to log the FFT data in real time. This permitted us to view the signal attributes without having to close any application. The data that were subsequently imported into the Matlab workspace permitted almost real-time analysis of the data.

For the purpose of teaching the neural network, RF signals containing data of various types of protocols were generated using both hardware and software platforms. Those RF signals were then transmitted and received at the DSP node. In the generation of those RF signals, for the modulation of analogue baseband signals, both analogue and digital modulation schemes were used. That is some of the analogue baseband signals were directly modulated as AM, FM, etc, and some baseband signals were converted to digital and modulated as ASK, PSK, etc. The baseband modulated signals were transmitted around 100 MHz frequencies and it was observed that the difficulties with noise were minimal and the transmission over a very short length used was efficient enough for all our purposes.

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