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Adaptation of Contemporary Design and Development Tools to Educational Procedure: A Case Study on the Design of Modern Signal Processing Systems

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Abstract: - The focus of this work is to demonstrate the employment of modern design and development tools, on the design and implementation of contemporary and complex signal processing systems. This approach aims to provide an alternative point of view in teaching state of the art systems with at-hand demonstration using real-life laboratory equipment. Specifically, the design and implementation of two composite projects, namely an OFDM transceiver and a Signature Verification system are shown. The design and implementation tools used for the latter projects are the TMS320C6713 DSK development kit from 'Texas Instrument Inc'. in conjunction with Matlab – Simulink from 'Mathworks Inc'.

Key-Words: - Education, OFDM, Signature Verification, Pattern Recognition, Matlab, TMS320C6713 DSK.

1 Introduction

The study, design and prototyping of contemporary signal processing systems involve several and often very complicated tasks that have to be solved. Specifically, definition of specifications and requirements, algorithmic design, system level design, simulation, implementation and finally verification are some of the steps that have to be followed [1][2]. Consequently, this methodology has to be entailed in the educational process so as to help students to appreciate the whole concept, besides only studying the fundamental principles.

Of course, it is apparent that such complicated projects demand the use of specialized and sophisticated hardware and software equipment. On the other hand, advanced software packages and hardware platforms allow the prospect of the before mentioned approach to be feasible [3].

The work in this paper demonstrates the system level design, simulation and implementation of two rather composite projects belonging to different scientific areas, which are, the system level design of an OFDM transceiver, from the field of multicarrier digital communications, and a Signature Verification system, from the field of pattern recognition [4][5][6][7]. This is achieved with the aid of modern tools, which are already widely spread in the educational community at low cost.

The design and simulation was made using Matlab -Simulink from 'Mathworks Inc.' while the implementation is done using the TMS320C6713 DSK development kit from 'Texas Instrument Inc.' The cooperation of Matlab IDE and Code Composer IDE allows for direct download of Simulink models to DSP code. It is interesting to note the importance of the above combinatorial use, in facilitating for a real-life implementation and evaluation rather than simulation only [3].

Additionally, such an approach like this, sets the scene for the implementation and quick set up of a complete experimental framework, where students or researchers can study and experiment on the whole range of signal processing systems. In general, besides only theoretical studying or subcomponents analysis, composite systems become feasible leading to a deeper understanding of new emerging technologies.

The paper is organized as follows: Section 2 presents the design of a baseband OFDM transceiver and endows with some indicative results of the system's functionality. Moreover, the general structure regarding several requirements is given, while specific tasks and specifications are discussed and analyzed. Section 3, provides the model design of the signature verification system and discusses its realization on the TMS320C6713 DSK development kit. Finally, section 4 deals with conclusions and discussion on further work.

2 OFDM system level design

The purpose of the presented design is a pedagogical approach to previously mentioned complicated issues, using state of the art design tools. Model development is parameterized in such a way to easily study and correlate the results for either educational or research purposes. Based on that, the models consist of a combination of either integrated software blocks or newly created ones. Furthermore, OFDM was chosen as a generalized concept of basic modulation schemes having a wide range of applications [1][2].

2.1 OFDM system parameters

The general structure of our framework is depicted in Fig. 1. The framework consists of the following basic parts: a) two personal computers which are used to transmit and receive data, b) two DSP boards that invoke the communication between the computers and c) an oscilloscope and/or spectrum analyzer for signal observation. Additionally, the implemented system is capable of transmitting raw text data, audio files and pictures. Moreover, we notice that due to hardware limitations and personal computer compatibility the operating frequency range of practical implementations is bounded by a sampling frequency Fs=44.1KHz.

The general structure of the implemented OFDM system is depicted in Fig. 2. The system level design was made using Matlab and Simulink. The implementation is done using the TMS320C6713 DSK development kit. The model consists of the following basic building blocks: a) Data generator as the bit stream source, b) QAM/PSK modulator for mapping bits to QAM/PSK values, c) IFFT for OFDM modulation, d) Cyclic prefix insertion and e) DAC for digital to analog conversion. In the current stage, the transceiver is adjusted to process text as binary source data.

The receiver consists of the reversed operation blocks along with synchronization and channel compensation blocks. The main design of an OFDM system involves specifying several parameters related to certain requirements set up by the propagation environment and the quality of service. Such requirements are the available bandwidth, the required bit rate and the tolerable delay spread. From these demands, we specify the OFDM symbol duration, thus the spacing of OFDM subcarriers. Further details can be found at [4][8]. The specifications for our model are summarized in Table 1. We see that some of them are tunable, providing flexibility for further development.

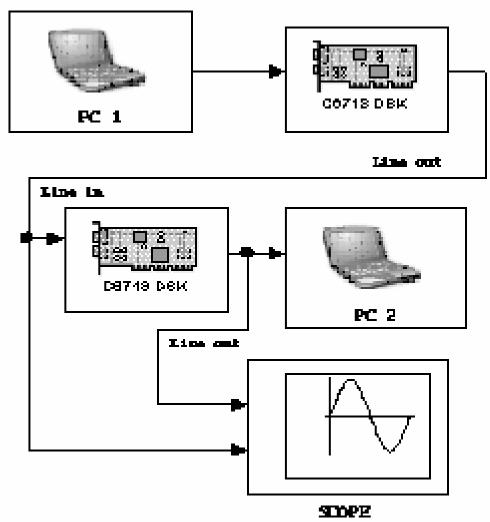

Fig. 1: General OFDM system design framework.

Furthermore, the structure of an OFDM frame involves a preamble pilot OFDM symbol, appended at the start of the data OFDM symbols. This known symbol is used for OFDM symbol time detection and channel estimation. Experimentation revealed that such a symbol is sufficient for a wired static communication channel which our system currently uses. The number of data OFDM symbols that constitute a frame is also tunable having a typical value between 400 to 500 OFDM symbols. Additionally, pilot subcarriers are embedded within the OFDM data symbols, providing the means for correct de-rotation of altered subcarriers due to synchronization impairments.

The resulted output OFDM signal from the

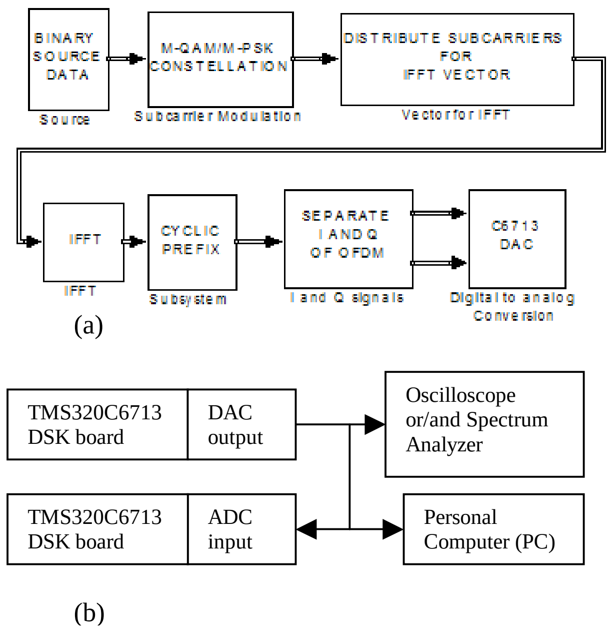

Fig 2: OFDM system: a) OFDM transmitter architecture, b) OFDM transceiver signal processing.

TMS320C6713 DSK board is observed by means of an oscilloscope and spectrum analyzer and stored to either a personal computer or a second DSP board for demodulation. The latter involves: a) detection of an incoming OFDM frame, b) estimation of OFDM symbol time, c) channel estimation, d) sampling frequency clock offset compensation, e) FFT demodulation and f) raw text data recovery.

PARAMETER	VALUE
Data rates	Tunable
Modulation	On-Off Keying and QPSK
Number of data subcarriers	Tunable
Sampling frequency (Fs)	44.1 KHz (Ksps)
FFT/IFFT size for 44.1Ksps (N)	128
OFDM useful symbol duration (IFFT/FFT interval)	$\frac{N}{Fs} = \frac{128}{44100} \approx 2.9m\sec$
Guard interval (T_{CP})	Tunable
Subcarrier spacing	$\frac{Fs}{N} = \frac{44100}{128} \approx 344.5Hz$
Signal bandwidth	Tunable
OFDM symbol duration	2.9msec+ T_{CP}

Table 1: OFDM system specifications.

It is worth to mention that the latter design approach easily introduces students to the concept of thinking modern communication systems as individual autonomous building blocks having tunable parameters and performing well-defined tasks.

2.2 OFDM system evaluation

Fig. 3 (a) and (b) depicts the case of 4 not adjacent and 15 adjacent unmodulated OFDM subcarrier generation respectively, while Fig. 4 (a) and (b) provides the modulation results when different data patterns of “on-off” keying modulation per subcarrier is used. Additionally, besides the corresponding spectrum for each case, the “in-phase” (I) and Quadrature (Q) for the time domain OFDM signal is also given. Furthermore, Fig. 5 (a) shows the case of QPSK modulation per subcarrier when a cyclically repeated data (QPSK symbol) pattern is used, while Fig. 5 (b) depicts the OFDM signal and spectrum for random (e.g. text) data transmission. The number of subcarriers was chosen to be 16 for illustrative purposes.

From the oscilloscope measurements we see that the design specifications, as they are defined from Table 1, are exactly met.

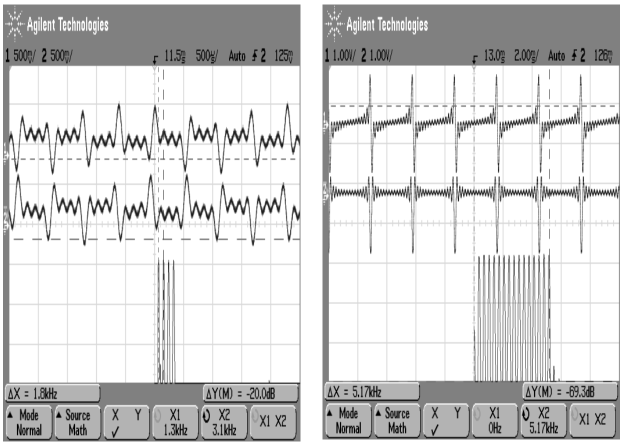

Fig 3: Case of OFDM unmodulated subcarrier generation: (a) 4 subcarriers (not adjacent), (b) 15 adjacent subcarriers.

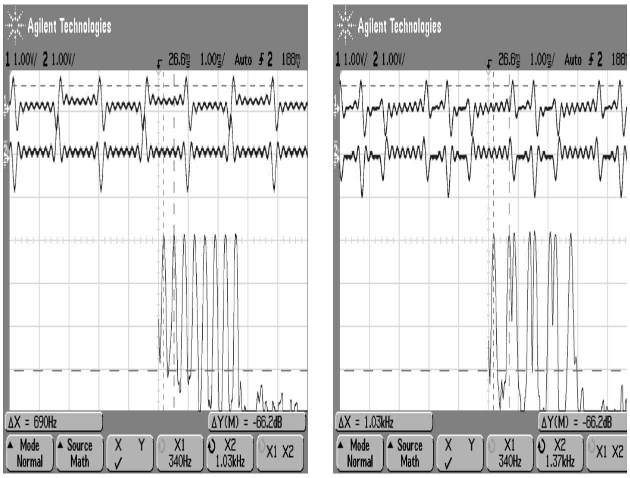

Fig 4: Case of OFDM On-Off Keying modulation,
(a) data stream = [1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0],
(b) data stream = [1 0 0 1 1 0 0 1 1 0 0 1 1 0 0 1].

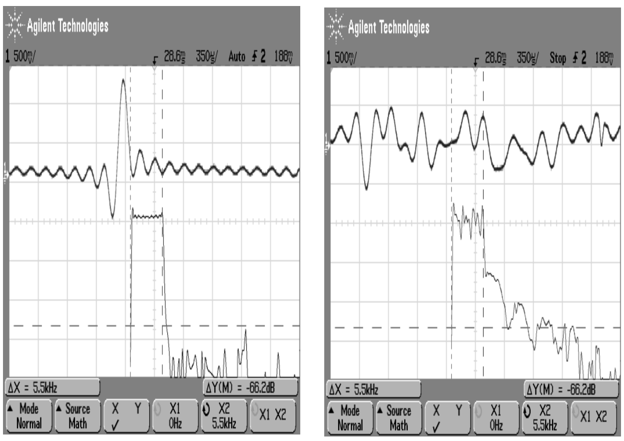

Fig 5: Case of OFDM QPSK modulation:
(a) data stream = [0 1 2 3 0 1 2 3 0 1 2 3 0 1 2 3],
(b) random data.

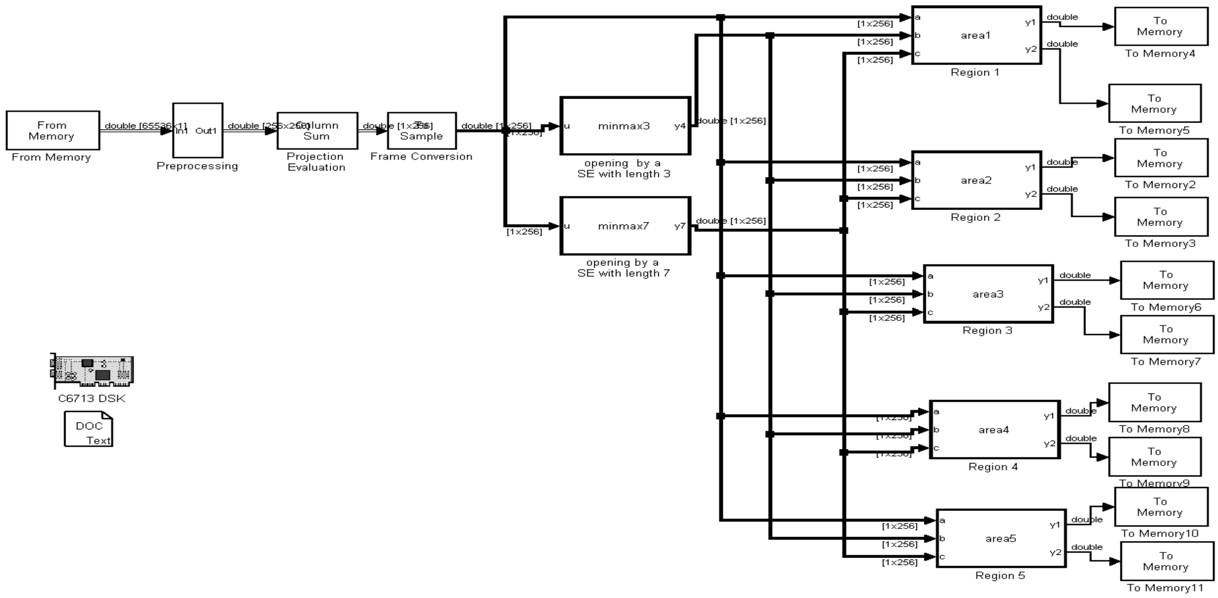

Fig 6: Feature extraction building blocks.

3 Signature Verification system design

In this section, the postulates of a pattern recognition system are demonstrated using a signature verification system as an example. This project has been employed since it comprises tasks from image processing and statistical data analysis like template matching. Although this concept is rather complicated, it introduces a student to appreciate the decomposition of a complex project into well-defined sub modules.

The characteristics and the extraction methodology for a feature vector and the overall design of signature verification system is described and realized using the TMS320C6713 DSP floating-point and Matlab-Simulink. As mentioned before, these tools comprise a nice framework for DSP implementation, which allows easy transition of students from theory to practice.

The methodology includes a) the preprocessing stage, b) feature extraction and c) training and classification.

The feature extraction method is based on morphologically processing the projections of simple or complicated curves, which are obtained from the binary signature samples. Morphological openings are applied to one-dimensional projection functions in order to control and measure the information from shapes and waveforms by means of granulometries [9]. The efficiency of features is evaluated using handwritten signatures on a large signature database. The signature database consists of 70 sets of different signatures. Each set consists of 105 genuine and 35 forgery signatures. The images have been scanned at a resolution of 100 dpi, 8 bit gray scale.

The image-processing algorithm, which transforms the original image to a multidimensional feature vector, is depicted in Fig. 6. The figure describes the Simulink building blocks that have been used in order to implement the proposed algorithm. First, we are using a ‘semi-gross’ preprocessing procedure in order to avoid problems, which could arise from various sources of the image (signature) creation. This semi-gross preprocessing includes thresholding in order to obtain a two-tone (black and white) image and edge detection in order to reject redundant pixels from the image. The double trace of the image after the edge detection algorithm carries the upper and lower profiles of the signature image, thus resulting to a clear and informative raw image data. A granulometric feature vector is employed in this work for signature representation [9]. It contains spatial information about the orientation of the line segments in a handwritten pattern. Fig. 6 also provides the entire proposed process as it has been imprinted to the Simulink model builder. This represents the primary image in a grey-level format and corresponds to a size of 256×256 pixels. The 65536 elements that have been stored to the memory are reshaped in order to represent a matrix of 256×256 double precision pixels. Then, the image is transferred to the pre-processing sub-procedure block. We notice here that

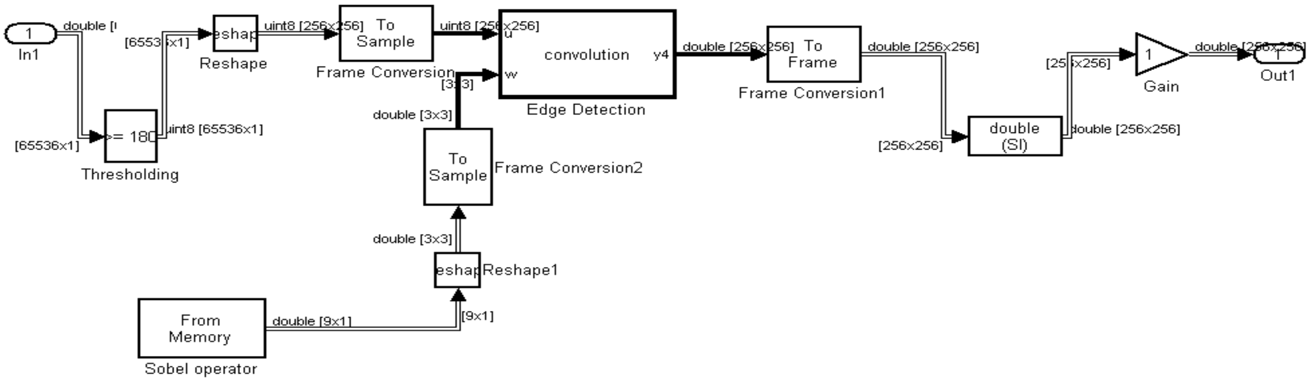

Fig 7: Thresholding and Edge Detection Sub-Blocks (Preprocessing stage).

the TMS320C6713 starter kit operates at 225MHz and provides a 16 MB SDRAM for data storage, which is enough for this kind of data manipulation. As Fig. 7 shows, the original image within this block is thresholded, while edge detection is applied afterwards. The final binary image is the signal, which will be processed in order to evaluate the ten-dimensional feature vector.

For each signature owner an individual classifier is designed, trained and evaluated for the case of random forgery. This design strategy offers reduction on the required training samples. Moreover, it can be applied in case that another writer is added to the verification procedure. For all cases, the classification criterion used is the weighted distance from the center m_i of each cluster. The classification rule assigns the test sample $\boldsymbol{x}$ into the class with the smallest distance.

Fig. 8 shows a system that has been built for a writer. The total SDRAM memory of the DSP kit is 16MB, indicating that all the 70 writers can be implemented into the DSK. The blocks of Fig 6, are embedded in the Feature Components Extraction subsystem. According to Fig. 8 an unknown specimen is acquired to the input of the DSK. Then, feature extraction is applied according to the material exposed to previous sections. The DSK is also supplied with the inverse covariance and the mean values of the i-writer class. Final, the extracted feature is used in order to evaluate both the weighted as well as the Euclidean distances from the mean of i-writer class. After evaluation of all possible classes, a minimum selection algorithm decides the class to be assigned to the unknown sample.

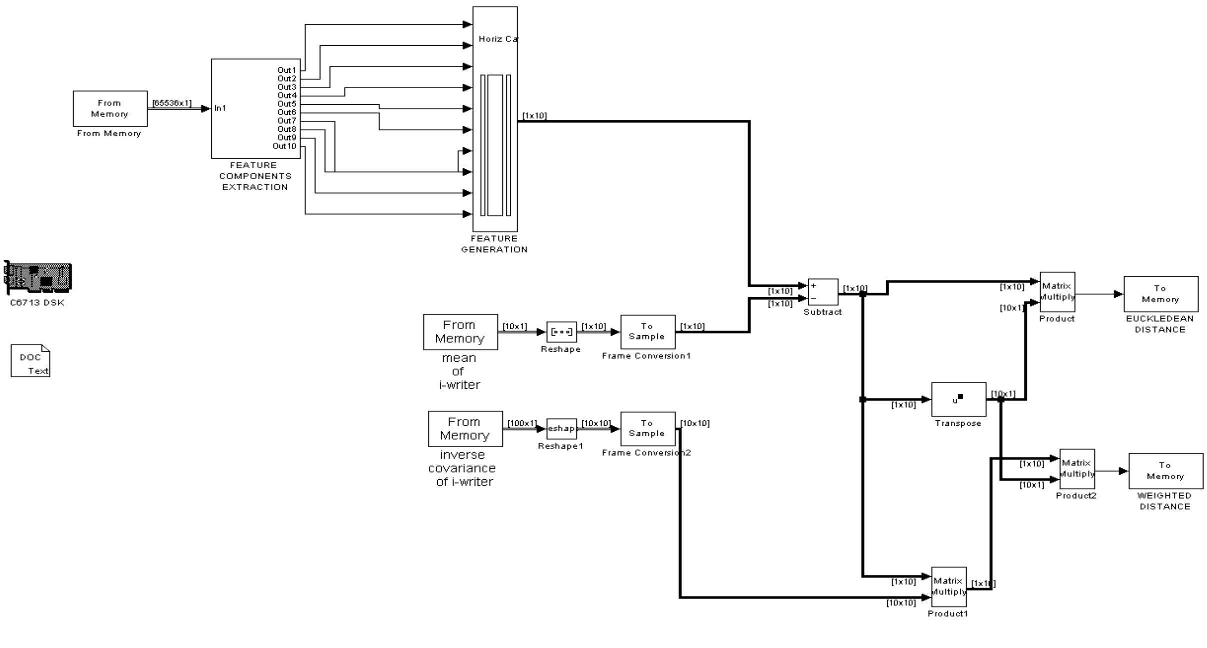

Fig 8: Discrimination Procedure for evaluation of the similarity measure.

4 Conclusion

In this paper we have presented an educational approach to the design, implementation and evaluation of contemporary signal processing systems. This was achieved through the demonstration of complicated modern systems such as an OFDM transceiver and a signature verification system using the TMS320C6713 DSK development kit in conjunction with Matlab-Simulink. This alternative approach allows students or even researchers to think, appreciate and evaluate composite contemporary systems as a set of well-defined building blocks. In overall, we have shown that the use of modern design tools results in a dynamic approach that can easily serve in the educational process. Future work involves the implementation of a complete flexible experimental framework for studying and prototyping several signal processing systems.

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