A MATLAB-BASED MAGNITUDE RESPONSE GAME FOR DSP EDUCATION

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ABSTRACT

We present a Matlab-based game, teaching the interplay between the pole-zero chart of a linear filter and its magnitude response. The estimation error, which acts as a game score, is based on concepts undergraduate students learn during elementary signal processing courses at our university. The game is accompanied by an online database collecting the players' results and admitting a statistical analysis thereof.

Index Terms— DSP education, gamification, magnitude response, Matlab

1. INTRODUCTION

Recent years have seen a tremendous effort in providing online courses for digital signal processing (DSP) eduction: The signal processing lens at Connexions[1] and the DSP courses by Richard Baraniuk on edX[2] or by Paolo Prandoni and Martin Vetterli on Coursera[3], cf. [1], are just the most recent examples. This effort is complemented by a series of online or computer-based *interactive* learning tools, which help the students gain intuition and knowledge at a hands-on basis. Among these tools are Matlab applications such as "Signals and Systems Using Matlab"[4] (SSUM, [2]) and the course material[5] to "DSP First" [3,4], Mathematica tutorials [5], and an online Java-based laboratory "J-DSP"[6] [6], which has recently been made available for iPhone and iPad [7].

More generally, i.e., neither restricted to DSP education nor to online or interactive courseware, the use of games has proved advantageous to increase student's motivation to learn – an effect called *gamification*; see, e.g., [8, 9] and the references therein. In particular, the positive effect of using a card game in a signal processing course was shown in [10]. What, to the best of our knowledge, is currently missing are online or computer-based learning *games*, motivating students to compete against each other in various DSP-related disciplines.

This work takes a first step to fill this gap: We present a Matlab-based learning game[7] in which the player has to estimate the magnitude response of a filter, given only its pole-zero chart. While in J-DSP, SSUM, and ZPGUI[8] the effect of the placement of the poles

and zeros on the magnitude response can be learned interactively, in our work the players are challenged to correctly apply this knowledge: They can compare their score to previous attempts, or to the score of other players via a central database. In addition to that, the tool allows the players to monitor their learning performance.

The purpose of this paper is to introduce the game and its features; a statistical analysis of its effect on students' performance is deferred to a later publication.

2. POSITIONING THE TOOL IN DSP EDUCATION AT GRAZ UNIVERSITY OF TECHNOLOGY

The elementary DSP course at Graz University of Technology is a fourth-semester bachelor course, mandatory for students of electrical engineering, telematics, biomedical engineering, and audio engineering. Between 350 and 400 students take this course every year. The lecture, taught either by Gernot Kubin or Klaus Witrisal, is accompanied by problem classes in which analytical examples are solved. The problem classes require students to work on home assignments, which are the basis for grading. The lecture is graded during a three-hour exam, which involves a theory part and a problem-solving part.

The frequency response, and in particular, the magnitude response, of a discrete-time, linear, time-invariant filter assumes an important position in the problem classes: Four of the eight units cover this topic, investigating the periodicity of the frequency response as well as its dependence on certain properties of filters, e.g., the all-pass or the linear-phase property.

One of these units is devoted to connecting the pole-zero chart of the transfer function to the magnitude response. Most textbooks follow a geometric approach, where the magnitude response at a specific frequency is related to the distances between the corresponding point on the unit circle and the poles and zeros of the transfer function [11–14]. This approach is entirely based on the complex z-plane alone. Contrarily, in our course we leave the z-plane, as, e.g., in [15, Ch. 6.3.2 & Fig. 6-21] or ZPGUI: The magnitude of the filter transfer function is a graph in a three-dimensional coordinate system. It defines a "mountainous area", where poles correspond to "peaks" and zeros to "valleys"; in this area, we "go on a hike along the unit circle" – the closer one is to a pole or zero, the more pronounced is the maximum or minimum of the magnitude response.

We believe that the concept of the magnitude response is well-understood by the students with help of the three-dimensional approach. This belief is supported by exam results, where in the problem-solving part the students have to draw *qualitatively* the magnitude response of a linear filter based on its pole-zero chart. To further improve the students' performance in this respect, the game presented in this work was developed during two bachelor's
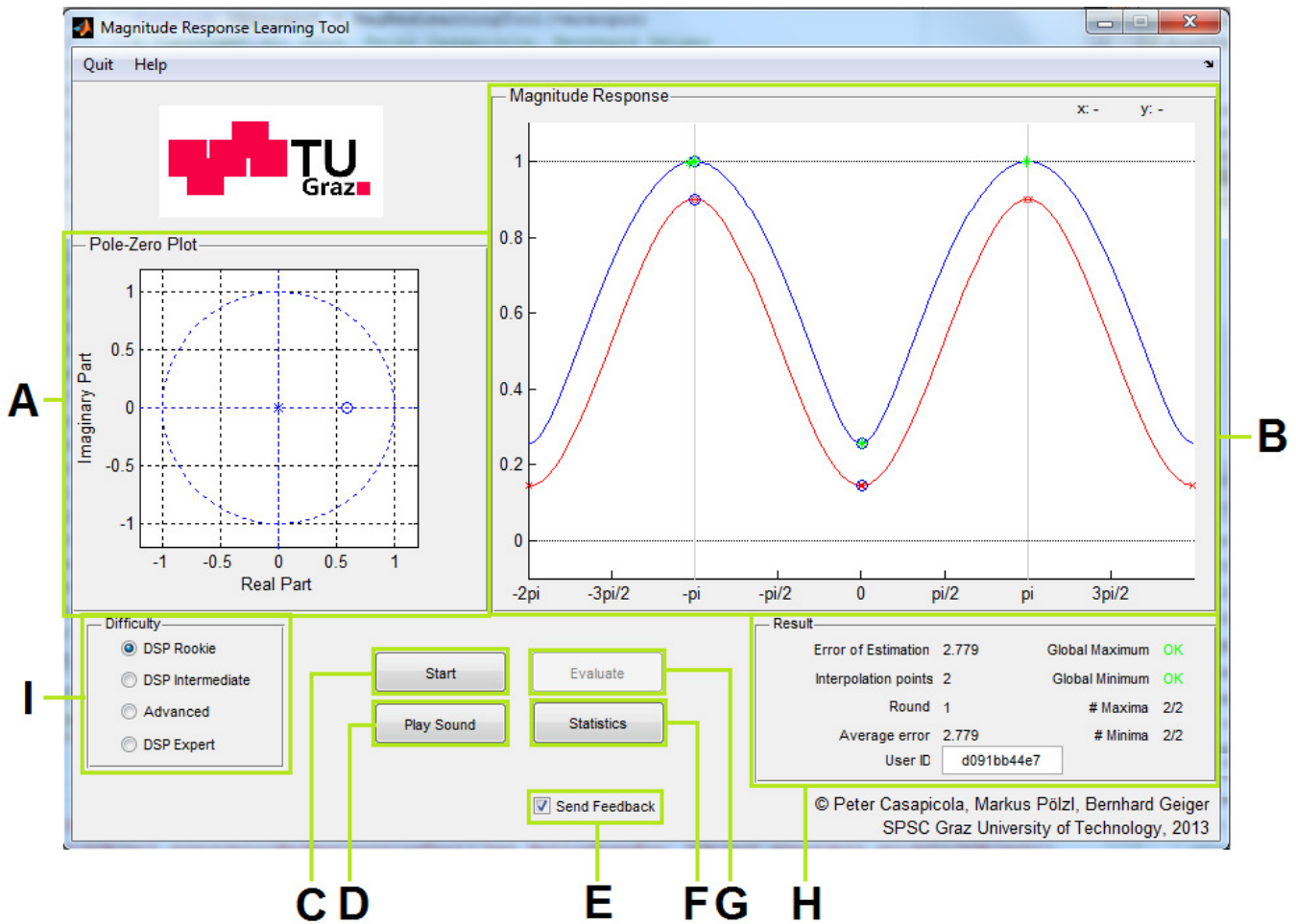

Fig. 1: Graphical User Interface of the Magnitude Response Game. For a description of the elements see the text of Section 3.1.

projects. We introduced the game in the problem classes of summer term 2013 and recommended it for exam preparation. Currently, exam statistics are collected to assess the game's effect on the students' ability to draw a magnitude response from a pole-zero chart. Additionally, an extensive survey on how the students experience the game is currently being planned.

Preliminary responses from students are quite positive. Prior to exams, students regularly use the game for preparation (cf. Fig. 4). For example, the 50 candidates of the 2013 summer exam played roughly 350 rounds during their preparation and submitted their results to the online database. Some students expressed interest to improve the game during a bachelor's project.

3. THE GAME

In each round of the game the player has to estimate the magnitude response of a filter with a given pole-zero chart. Depending on the selected difficulty, a filter subtype (low-pass or high-pass, all-pole or all-zero, first or second order, etc.) is chosen with random parameters. After the player specified an arbitrary number of interpolation points, the estimated magnitude response is compared to the true magnitude response. The evaluation results are stored on the player's computer and, optionally, in a central database hosted at our

institute's server.

3.1. Graphical User Interface

In Fig. 1 the graphical user interface is shown. The most important part is the magnitude response chart (B). If located in this field, the standard cursor will be replaced with a crosshair. The cursor coordinates are indicated in the top right of the chart (x: / y:).

At the beginning of every round the chart is empty. Based on the pole-zero chart (A; see below) and the assumption that the global maximum is normalized to 1, the player has to estimate the magnitude response of the system and draw it in the chart by placing interpolation points with a left mouse click. After every click, the interpolation points (red crosses, $+$) are interpolated using piecewise cubic interpolation and extended periodically by 2π (red line; Matlab command `interp1`). A right mouse click removes the last interpolation point.

After pressing the evaluation button (G) or by pressing the Enter-key, a blue curve will show the true magnitude response and its extreme values. Global maxima and minima are shown as blue circles $\circ$, local maxima and minima are represented by a green star $*$. The true and estimated magnitude response are compared to each other; the evaluation results are displayed on the score board (H) and stored for statistical analysis.
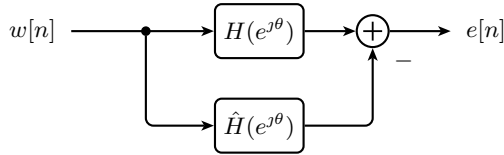
Fig. 2: System model for the estimation error $e[n]$; H and $\hat{H}$ are the true and estimated filters, and $w[n]$ is a white noise sequence with variance $\sigma_w^2 = 100$.

Further elements of the graphical user interface are:

(A) The pole-zero chart of the predefined filter. Poles are indicated as $\times$, zeroes are shown as $\circ$.

(C) Start button; This one starts a new round.

(D) Pressing this button plays an audio file before and after applying the filter. This should help the player get intuition for low-, high-, and band-pass characteristics.

(E) This checkbox toggles on or off automated feedback of the evaluation results to the online database.

(F) Provides statistical evaluation about the player's previous attempts (see Section 4 and Fig. 3).

(G) Evaluates the estimated magnitude response. This button is only enabled after pressing the start button, and disabled when the user activated an evaluation. The Enter-key will also evaluate the estimated points.

(H) Score board. It contains the evaluation results comparing the true and the estimated magnitude response, including the number of interpolation points set by the player, and whether or not the position and/or number of global and local extremes have been identified correctly. The *error of estimation*, computed according to Section 3.2, is an indicator of how close the estimated magnitude response is to the true one. The *average error* is obtained by averaging this quantity over the number of rounds. Finally, the *UserID* is a unique string generated randomly the first time the player starts the game. It identifies database entries with the player and allows (anonymous) high-score lists and player-vs-player comparisons (see Section 4).

(I) Difficulty selection. The player can choose from four difficulty levels, each containing eight different filter types. In every round, the filter type is randomly chosen. The difficulty can only be changed between two rounds. In all difficulties the estimated magnitude response is extended 2π-periodically; in the difficulties *DSP Rookie* and *DSP Intermediate*, where only real-valued filters are used, the magnitude response is also extended symmetrically.

3.2. Estimation Error

Since the DSP course at our university includes the topic of round-off noise in digital filters, the noise gain of a system is a concept known to the students. Therefore, we decided to base the estimation error on this concept and to include the following derivation in the short manual of the tool for didactic reasons.

The estimation error is the noise gain of the difference system (see Fig. 2), where it is assumed that both constituting systems have the same phase response. Thus, with

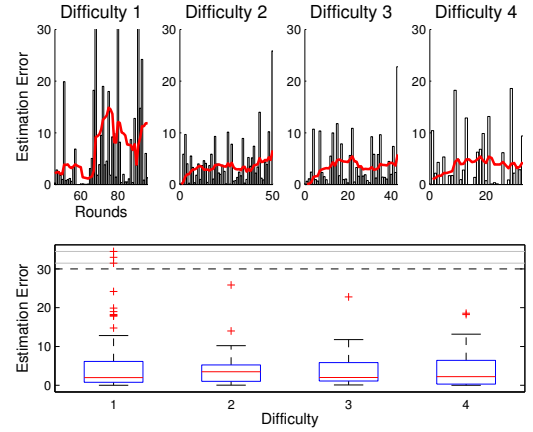$$\varphi := \angle\hat{H}(e^{j\theta}) = \angle H(e^{j\theta})$$

Fig. 3: Statistical evaluation provided by the game.

and with $w[n]$ being white noise with variance σ_w^2, the variance σ_e^2 of the estimation error $e[n]$ computes to

$$\sigma_e^2 = \frac{\sigma_w^2}{2\pi} \int_{-\pi}^{\pi} |H(e^{j\theta}) - \hat{H}(e^{j\theta})|^2 \, d\theta$$

$$= \frac{\sigma_w^2}{2\pi} \int_{-\pi}^{\pi} \left||H(e^{j\theta})|e^{j\varphi} - |\hat{H}(e^{j\theta})|e^{j\varphi}\right|^2 \, d\theta$$

$$= \frac{\sigma_w^2}{2\pi} \int_{-\pi}^{\pi} \underbrace{|e^{j\varphi}|^2}_{=1} \left||H(e^{j\theta})| - |\hat{H}(e^{j\theta})|\right|^2 \, d\theta.$$

The last line shows that our definition for the estimation error is adequate, since it equals the squared distance between the true and estimated magnitude response. In order to get a meaningful scale for the estimation error, the input variance σ_w^2 was set to 100.

4. STATISTICAL EVALUATION AND HIGHSCORE

For each round, the results displayed in the score board (H in Fig. 1) are saved in a local file as comma-separated values. If the player permits, the same results are transmitted to an online database where they are stored with a time-stamp and the unique user ID.

The players have two possibilities to track their performance: The first depends only on data stored locally and can be accessed directly from the game (F in Fig. 1). It consists of a boxplot showing, for each difficulty, the estimation error of all previous attempts. In addition, four bar plots show the estimation error over the last 50 played rounds, together with a red line indicating the average over the last ten rounds (see Fig. 3).

The second possibility is based on the performance of multiple players stored in the online database. On the game's webpage (Fig. 4), for each difficulty level, the top ten results are displayed together with a time stamp and the unique user ID. In addition, the usage statistics, i.e., the number of total rounds played per day, are displayed using Highcharts JS[9], a JavaScript charting library available under the Creative Commons license. A different webpage shows a boxplot based on all entries in the server's database, see Fig. 5. After entering their user ID in the specified field, the players can compare their performance to the average performance of all other players.
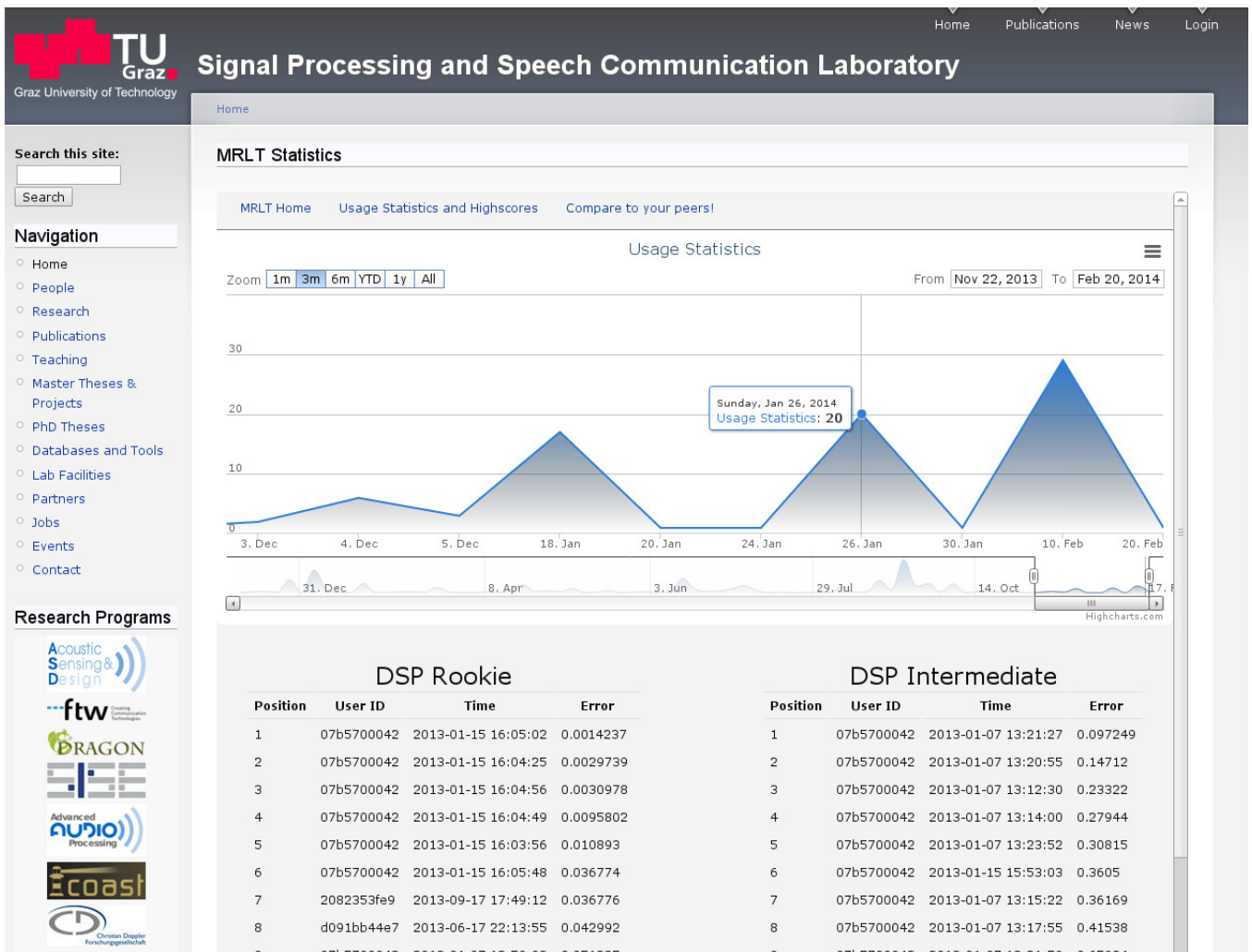
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[9]http://www.highcharts.com/

Fig. 4: Screenshot of the webpage displaying high-scores and usage statistics. Peaks in the usage statistics correspond to students preparing for the end-of-semester exam.

Additionally, the webpage allows the comparison of two players' boxplots by entering two user IDs.
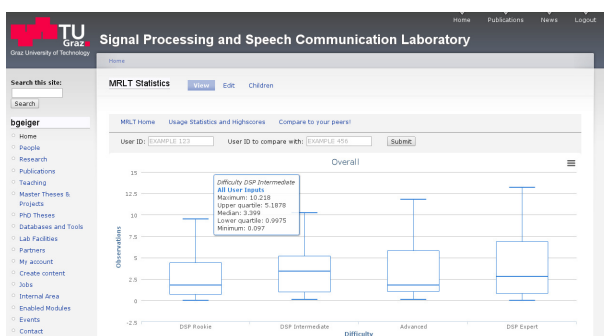

Fig. 5: Screenshot of the webpage showing boxplots based on all database entries. This webpage also allows player-vs-database and player-vs-player comparisons.

5. CONCLUSION

We presented a Matlab-based teaching game in which the player has to estimate the magnitude response of a linear filter specified only by its pole-zero chart. The game score – the difference between the true and the estimated magnitude responses – is based on knowledge the player has obtained during the elementary DSP lecture at our university. Game results are stored locally on the player's computer and in an online database, admitting local and web-based statistical evaluation of the results.

As a next step we will investigate the effect of using this tool on the students' performance in corresponding exam problems. Whether other DSP-related topics can also benefit from Matlab-based teaching games is the object of future investigation.

6. ACKNOWLEDGMENTS

7. REFERENCES

[1] D. H. Johnson, P. Prandoni, P. C. Pinto, and M. Vetterli, "Teaching signal processing online: A report from the trenches," in *Proc. IEEE Int. Conf. on Acoustics, Speech and Signal Processing (ICASSP)*, May 2013, pp. 8786–8790.

[2] B. L. Sturm and J. D. Gibson, "Signals and systems using MATLAB: An integrated suite of applications for exploring and teaching media signal processing," in *Proc. Annual Conf. on Frontiers in Education (FIE)*, Oct. 2005, pp. F2E–21.

[3] J. H. McClellan, R. W. Shafer, and M. A. Yoder, *DSP first: A multimedia approach*, Prentice Hall, Upper Saddle River, NJ, 1997.

[4] J. H. McClellan, R. W. Schafer, J. B. Schodorf, and M. A. Yoder, "Multi-media and world wide web resources for teaching DSP," in *Proc. of Int. Conf. on Acoustics, Speech, and Signal Processing (ICASSP)*, May 1996, vol. 2, pp. 1101–1104 vol. 2.

[5] B. L. Evans, L. J. Karam, K. A. West, and J. H. McClellan, "Learning signals and systems with Mathematica," *IEEE Trans. Educ.*, vol. 36, no. 1, pp. 72–78, Feb. 1993.

[6] A. Spanias and V. Atti, "Interactive online undergraduate laboratories using J-DSP," *IEEE Trans. Educ.*, vol. 48, no. 4, pp. 735–749, Nov. 2005.

[7] J. Liu, S. Hu, J. J. Thiagarajan, X. Zhang, S. Ranganath, M. K. Banavar, and A. Spanias, "Interactive DSP laboratories on mobile phones and tablets," in *Proc. IEEE Int. Conf. on Acoustics, Speech and Signal Processing (ICASSP)*, Mar. 2012, pp. 2761–2764.

[8] J. J. Lee and J. Hammer, "Gamification in education: What, how, why bother?," *Academic Exchange Quarterly*, vol. 15, no. 2, 2011.

[9] S. Gareau and R. Guo, "'All work and no play' reconsidered: The use of games to promote motivation and engagement in instruction," *International Journal for the Scholarship of Teaching and Learning*, vol. 3, no. 1, 2009.

[10] A. S. King and R. K. Martin, "The benefits of game use in a signal processing graduate class," in *Proc. IEEE Int. Conf. on Acoustics, Speech and Signal Processing (ICASSP)*, Mar. 2012, pp. 2753–2756.

[11] A. V. Oppenheim and R. W. Schafer, *Discrete-Time Signal Processing*, Pearson Higher Ed., Upper Saddle River, NJ, 3 edition, 2010.

[12] P. S. R. Diniz, E. A. B. da Silva, and S. L. Netto, *Digital Signal Processing: System Analysis and Design*, Cambridge University Press, Cambridge, 2 edition, 2010.

[13] S. K. Mitra, *Digital Signal Processing: A Computer-Based Approach*, McGraw Hill, New York, NY, 3 edition, 2006.

[14] A. Papoulis, *Circuits and Systems: A Modern Approach*, Holt-Saunders, New York, NY, 1981.

[15] R. G. Lyons, *Understanding Digital Signal Processing*, Prentice Hall, Upper Saddle River, NJ, 2 edition, 2004.