Experiences with Web-based Signal Analysis Laboratories and Online Training during the COVID-19 Period

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***Abstract*—This work in progress paper describes our efforts and challenges in delivering undergraduate and graduate courses during COVID-19 conditions. More specifically, we focus on the adaptation and delivery of digital signal analysis laboratories for all the remote learners during the pandemic conditions. Methods for online labs and workforce training have been developed and deployed on a virtual basis. These labs and simulation environments have been deployed in signals and systems and DSP classes as well as in workforce development programs such as the REU and RET. The assessment of these efforts included evaluation forms and interviews. Challenges and opportunities from virtual delivery of content and labs were also part of the assessment.**

Keywords—COVID-19 education, virtual labs, machine learning, DSP, workforce, REU, quantum computing

I. INTRODUCTION

COVID-19 conditions resulted in major changes in undergraduate and graduate education and several institutions adapted their programs to offer courses online. Virtual labs [1-6] have been previously proposed in a variety of disciplines even before the pandemic, however laboratory-based education went through adaptation in the Spring of 2020. This paper describes our efforts to deliver online laboratory and hands-on training experiences during the COVID-19 period. The restrictions of the pandemic created challenges and opportunities in delivering impactful experiences through synchronous and asynchronous media. Although the delivery of lectures, flipped classes, and online presentations have been covered and assessed before, the delivery of hands on experiences and web laboratories in certain areas requires further analysis. Firstly, the comprehensive delivery and assessment of laboratory experiences across different regions and audiences require technology and content adaptation. Secondly, these processes require assessment and feedback for continuous improvement. The paper describes experiences in the development and delivery of signal analysis and machine learning (ML) tools that enable hands on experiences and labs. A series of online exercises and the pertinent software technology are described along with learning objectives and planned assessments. Virtual labs have been used in curriculum and workforce development programs including: a) undergraduate signal analysis and DSP classes and b) NSF research experiences for undergraduates (REU) and for teachers (RET). Preliminary assessments are provided.

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The use of a graphical block diagram-based system approach using HTML5 J-DSP technologies [3] is described and details are given on delivering interactive hands-on experiences with such a system. The graphical software interfaces include user-friendly signal analysis algorithms such as filters, fast Fourier transforms, signal conditioning, spectrograms and frame by frame speech processing. Participants use these functions to perform experiments on real life signals and reinforce ideas learned in signals and systems classes. The interactive machine learning functions provide access to feature extraction, clustering algorithms (k-means), and neural networks that can be used in applications such as voice recognition and data analytics. Laboratory exercises that engage these functions during the COVID-19 period have been assigned in both online classroom settings and workforce training settings.

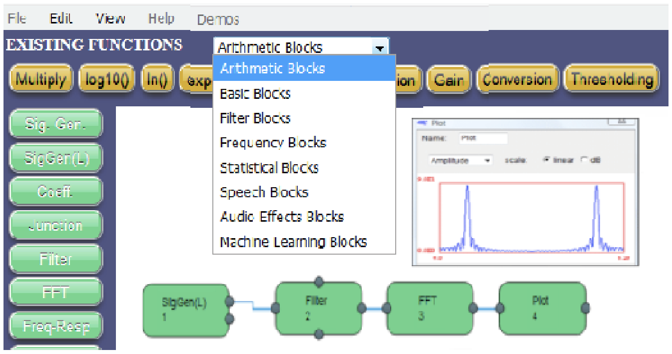
To assess the impact of all the designed online functions and training exercises, an evaluation process with online questionnaires was developed. Preliminary results from these assessments are reported in this WIP paper. Additional results will be obtained in the Summer and Fall of 2021.

II. VIRTUAL LABS AND OBJECT ORIENTED TOOLS

The use of online tools in signals and systems and in engineering education at large has been documented in several research endeavors [5-7]. In our group we developed in the mid-2000s an object-oriented J-DSP [6] tool which we updated for modern browsers [2]. The tool consists of an environment called J-DSP HTML-5 that allows students to build online simulations as a block diagram with connections symbolizing signal flow and blocks embedding functions such as filters, Fourier transforms, statistical signal analysis and more specialized functions working on real life signals (Fig. 1). A user can build simple filter and system design simulations and also run advanced DSP functions. These functions have been used during the COVID-19 period in virtual laboratories. We will discuss in a subsequent section, specialized functions as work in progress with planned audio signal analysis and Quantum ML functions.

The platform in Fig. 1, was deployed in the sophomore signals and systems course, in the senior Digital Signal Processing, and in the junior Digital Culture and Arts class.

Advanced functions of this virtual simulation software were also deployed in select undergraduate and graduate classes at two universities including ours. The system is not platform specific and works on all web browsers and hence it can be accessed anytime/anywhere. The software has also been deployed in workforce development programs to pre-train students and teachers in signal processing and ML algorithms. The use of this system was ideal during the COVID-19 period as it worked well both for instructors with share screen functions of zoom and with other teleconferencing platforms.



Fig, 1. Object Oriented Platform for Signal Analysis.

A. *Functions of the Online Simulation Program*

The virtual simulation program has an array of functions that can be used for signals and systems analysis, digital signal processing, random signal analysis, speech and audio processing, adaptive signal processing and machine learning.

Sample simulations supporting lab exercises include:

- Simulations and design of FIR and IIR Filters.
- Filter impulse response and frequency response.
- Computing pole-zero z plane representations.
- Computing Fourier transforms using the FFT.
- Computing correlations and power spectrum.

The above capabilities which are available online were used during the COVID-19 period for virtual laboratories, homework, and computer projects. Advanced functions in the virtual lab include:

- Computation of linear prediction coefficients.
- Evaluation of speech signal correlations.
- Machine learning implementations of k-means
- Implementation of neural networks.
- Audio sound recognition

III. Workshop On Virtual Labs

A workshop was held in April 2021 to summarize the activities associated with all our virtual laboratories during the COVID 19 period. The workshop had several presentations from the developers of the virtual J-DSP laboratory and it also covered planned extensions in the laboratory. The workshop started with a description of the basic functions, their assessments, the interactions in the laboratory and the use of the program in virtual laboratories during the COVID-19 period. It then continued with a presentation on device localization, presentations on digit and phoneme recognition using ML which was deployed in our classes, and presentation on simulations and labs with hardware sensors. Finally the workshop closed with two proposals for additional functions, one on quantum computing and one on the use of audio spectrum features with ML for diagnostics on breathing abnormalities. All of the presentations included demonstrating virtual live simulations. Some of these presentations included preliminary assessment results. The workshop addressed specifically the impact of COVID-19 in education and the utility of the virtual labs in delivering laboratory experiences.

IV. Virtual ML Simulations For Workforce Programs

The Virtual J-DSP labs were also used in our 2020 summer workforce development training. More specifically, we introduced students from the REU and IRES programs [7-8] and teachers from the RET program [9] to ML using J-DSP. This program included tasks for recognizing phonemes using linear prediction and the k-means algorithm (Fig. 2).

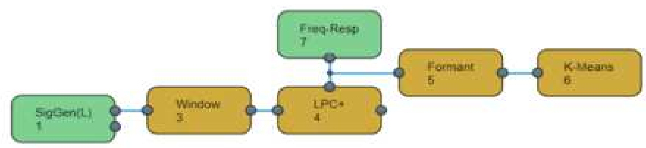


Fig. 2. Online Machine Learning simulation used in the bootcamp of the REU and RET programs during in 2020.

The REU, IRES and RET participants used the ML virtual online simulation as an introduction to clustering for phoneme recognition purposes. The simulation provided an introductory experience in signal processing and machine learning where REU and RET participants simulated a ML algorithm, obtained a confusion matrix [10-14], and documented the performance of the k-means algorithm with and without noise. At the same time the workforce development participants received a series of online lectures on spectral methods for extracting phoneme features and also a primer on machine learning. The virtual ML simulation provided the participants with a hands-on experience which later became very useful in applying these tools to other forms of data.

V. Work In Progress

The virtual platform will undergo further development for future functionality. There were two topics that were discussed in the aforementioned workshop. These are: a) development of functions for Quantum signal processing and machine learning simulations [15,16], and b) the development of spectrogram features [17-20] for diagnosing breathing and coughing disorders. Understanding the basics of quantum simulations can be accelerated using the J-DSP platform. On the other hand, coughing diagnostics will make use of NN technologies which again can be introduced in classes easily with J-DSP.

A. *Work in Progress in Quantum Signal Processing - Introduction in Undergraduate Classes using J-DSP*

Quantum computing promises to achieve an exponential speed over conventional computers. Estimates point to 100 million faster computations which will solve several problems in big data analytics and other areas. Quantum computing research and development is also a white house priority initiative. Nevertheless, quantum computers at their infancy stage, they are very expensive, and at this point the face several problems including Qubit deciphering errors and intolerance to mechanical vibrations. Despite the above, workforce development in quantum computing is essential and, in that context, we begun considering introducing first simple quantum simulations in an object-oriented environment to introduce and expose students to the basics of quantum signal/data processing. In this context, we are planning implementation of filters and later ML using quantum simulation models implemented in J-DSP. The advantage is that these models can run on a classical computing system. Building blocks in J-DSP of a quantum simulation system will be developed and at least one laboratory exercise will be deployed and assessed in signals and systems and DSP classes. An envisioned J-DSP simulation is shown in Fig. 3.

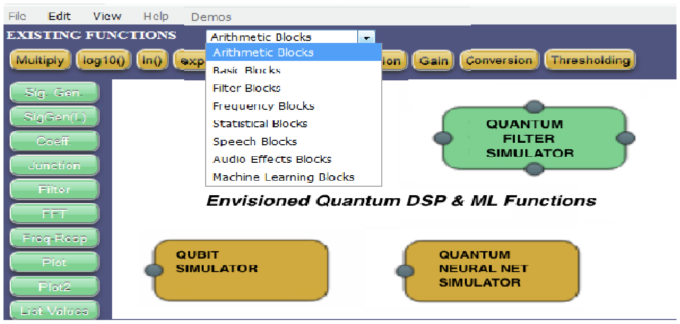


Fig. 3. Envisioned virtual lab functions for quantum machine learning.

The simulation will enable students to understand basic concepts in quantum computing, analyze qubit errors, and run quantum ML and quantum DSP functions. An exercise will be designed, deployed, and assessed in class. These functions will also be used in our REU programs to train students in this area. Work has already begun, and a preliminary system will be available in the late fall of 2021. The details of this endeavor will be reported in 2022 where a prototype will be disseminated and assessed in our classes.

B. *Work in Progress– Education on Spectrogram Features and ML / Neural Networks for Breathing Diagnostics*

One of the outcomes of the aforementioned workshop (Section III) was a series of recommendations by faculty and students to increase the functionality of the virtual lab to expose undergraduate students to new applications, such as those involving ML methods. We were also encouraged by the fact that ML (and AI) is one of the white house research and education initiatives and even specific recommendations made in starting workforce development programs in this area. Our team launched an effort to introduce an activity in our classes in audio pattern recognition using spectral methods and ML. This will build on existing FFT based virtual labs. Using ML and specifically neural networks (NN) to detect and classify different sounds has been studied for several years. It is our intend to build on previous work of ours and develop specific J-DSP functions (Fig.4) to recognize breathing and coughing audio patterns using neural networks. Building virtual labs in this area will enable students to apply DSP concepts and NN in diagnostics for COVID-19 audio coughing patterns [21-26]. We have obtained open source and anonymous databases containing coughing audio data which can be used for COVID-19 detection. Using these new functions, students and workforce development participants will learn how to apply ML and spectrogram tools in a compelling application of wide interest. These methods can also be used in recognizing other types of sounds relating to other applications. These functions will also be of value in ML workforce development programs. Once these functions are completed, they will be deployed and assessed. All data will be anonymous, and assessment will be carried by our university CREST evaluation organization.

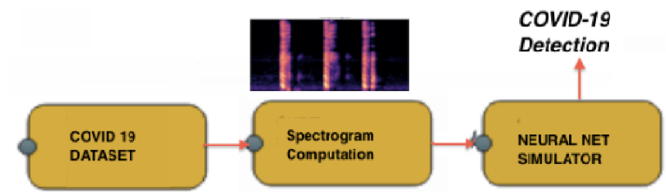


Fig 4. Work in progress in new spectral and NN function development. Envisioned functions include extracting spectrogram features, using neural networks, and detecting COVID-19 cough or other breathing abnormalities.

VI. Preliminary Assesments

The virtual labs were assessed in the 2020-21 academic year in the DSP class. An anonymous online questionnaire developed with questions relating to online access, ease of use, quality of labs, DSP concept understanding, ML lab effectiveness, and requests for suggestion for improvements. In general, the evaluations were positive and about 80 % of the students were satisfied with the lab experience. About 10% reported minor software bugs. Suggestions for improvements were also provided. Pre- and post-assessment instruments for specific topics are being developed by our university assessment organization. Detailed statistics of all the assessments will be presented at the conference including data collected in the summer of 2021.

VII. Conclusions

In this work in progress paper, we describe the use of a virtual DSP lab in undergraduate classes and workforce training programs during the COVID-19 period. The programs enabled instructors to run their classes and labs virtually. A preliminary assessment was carried out in the 2020-21 academic year and results revealed general student satisfaction with several aspects of the virtual lab. In addition, work in progress plans were described to expand functionality and include modern labs in quantum ML and also on spectral methods for COVID-19 non-invasive diagnostics. The labs will be reassessed in summer 2021 classes and summer workforce development programs and additional evaluations will be presented at the conference.

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