Toward the Army's Science and Technology Career

Successful First Steps from the Army's Science and Engineering Apprenticeship Program for High School Students

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How I got here – my education

- Twelve years of public-school education
- Currently a rising senior at Chantilly High School, Fairfax County, Virginia
- Applying for colleges!
- Most likely to study electrical engineering, applied physics or mechanical engineering

How I got here – spring of 2017

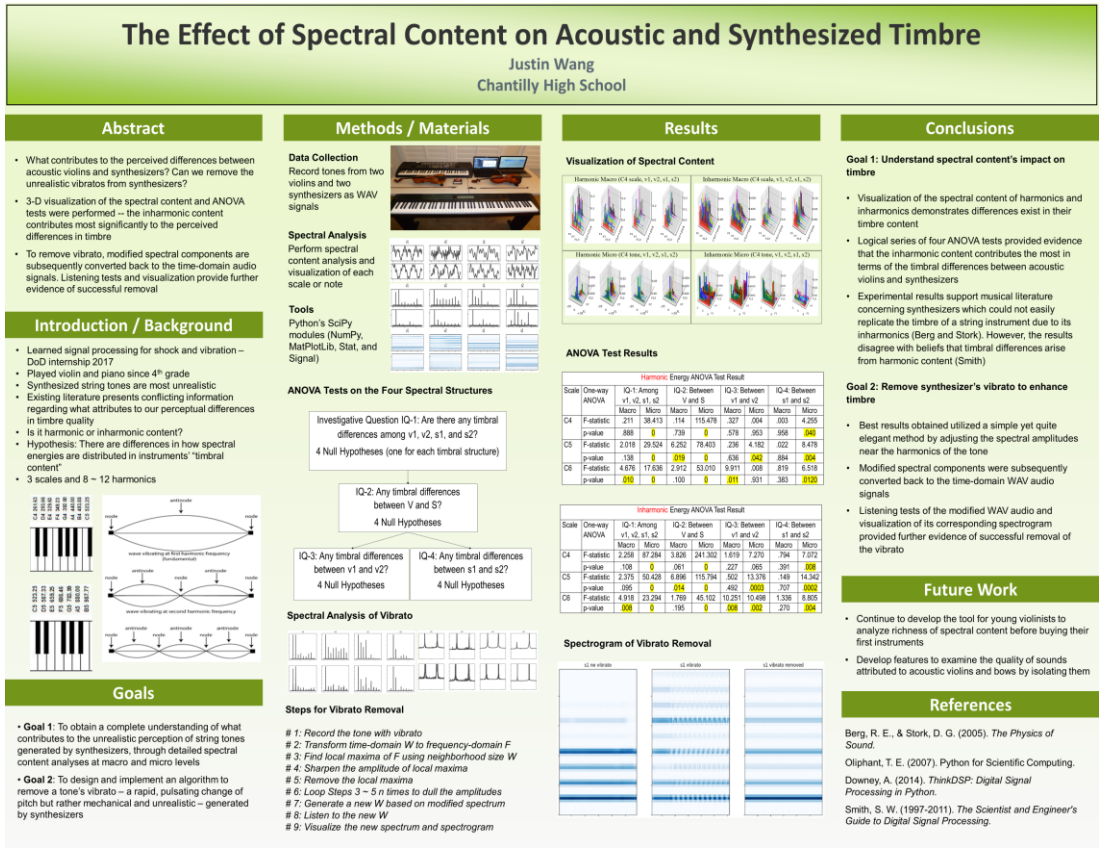
- Are unexplainable lab results always due to “instrumentation error?”
- Is that the real lab experience?
- Wanted to know what STEM research is like in a real lab
- AEOP’s Science and Engineering Apprenticeship Program (SEAP)
- Will they take me? I really don’t have much to offer!

A turning point – summer of 2017

- ARL and my mentor took me!
- Assignment: port Matlab-based shock-and-vibration toolbox into Python
- Mentor taught me about basics of signal processing
- Solid 8 weeks of work wrestling with Python
- At the end of summer, started working on a sound-puzzle that mystified me for more than 8 years

Many pleasant surprises – my junior year

- Won grand prize at Northern VA Science Fair → Intel ISEF finalist
- Won 1st place at Virginia State Junior Science and Humanities Symposium (JSHS)
- Won 2nd place (physics category) at National JSHS
- Army S & T Symposium invited me to share my journey of science exploration (education outreach)



The Effect of Spectral Content on Acoustic and Synthesized Timbre

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Abstract

- What contributes to the perceived differences between acoustic violins and synthesizers? Can we remove the unrealistic vibratos from synthesizers?
- 3-D visualization of the spectral content and ANOVA tests were performed -- the inharmonic content contributes most significantly to the perceived differences in timbre
- To remove vibrato, modified spectral components are subsequently converted back to the time-domain audio signals. Listening tests and visualization provide further evidence of successful removal

Introduction / Background

- Learned signal processing for shock and vibration – DoD internship 2017
- Played violin and piano since 4th grade
- Synthesized string tones are most unrealistic
- Existing literature presents conflicting information regarding what attributes to our perceptual differences in timbre quality
- Is it harmonic or inharmonic content?
- Hypothesis: There are differences in how spectral energies are distributed in instruments' "timbral content"
- 3 scales and 8 ~ 12 harmonics

Goals

- **Goal 1**: To obtain a complete understanding of what contributes to the unrealistic perception of string tones generated by synthesizers, through detailed spectral content analyses at macro and micro levels
- **Goal 2**: To design and implement an algorithm to remove a tone's vibrato – a rapid, pulsating change of pitch but rather mechanical and unrealistic – generated by synthesizers

Methods / Materials

Data Collection
Record tones from two violins and two synthesizers as WAV signals

Spectral Analysis
Perform spectral content analysis and visualization of each scale or note

Tools
Python's SciPy modules (NumPy, MatPlotLib, Stat, and Signal)

ANOVA Tests on the Four Spectral Structures

Investigative Question IQ-1: Are there any timbral differences among v1, v2, s1, and s2?
4 Null Hypotheses (one for each timbral structure)

IQ-2: Any timbral differences between V and S?
4 Null Hypotheses

IQ-3: Any timbral differences between v1 and v2?
4 Null Hypotheses

IQ-4: Any timbral differences between s1 and s2?
4 Null Hypotheses

Spectral Analysis of Vibrato

Steps for Vibrato Removal

 # 1: Record the tone with vibrato
 # 2: Transform time-domain W to frequency-domain F
 # 3: Find local maxima of F using neighborhood size W
 # 4: Sharpen the amplitude of local maxima
 # 5: Remove the local maxima
 # 6: Loop Steps 3 ~ 5 n times to dull the amplitudes
 # 7: Generate a new W based on modified spectrum
 # 8: Listen to the new W
 # 9: Visualize the new spectrum and spectrogram

Results

Visualization of Spectral Content

ANOVA Test Results

Harmonic Energy ANOVA Test Result

Scale	One-way ANOVA	IQ-1: Among v1, v2, s1, s2		IQ-2: Between V and S		IQ-3: Between v1 and v2		IQ-4: Between s1 and s2	
		Macro	Micro	Macro	Micro	Macro	Micro	Macro	Micro
C4	F-statistic	.211	38.413	.114	115.478	.327	.004	.003	4.255
	p-value	.888	0	.739	0	.578	.953	.958	.048
C5	F-statistic	2.018	29.524	6.252	79.483	.236	4.182	.022	8.478
	p-value	.138	0	.019	0	.636	.042	.884	.004
C6	F-statistic	4.676	17.636	2.912	53.010	9.911	.008	.819	6.518
	p-value	.010	0	.100	0	.011	.931	.383	.0120

Inharmonic Energy ANOVA Test Result

Scale	One-way ANOVA	IQ-1: Among v1, v2, s1, s2		IQ-2: Between V and S		IQ-3: Between v1 and v2		IQ-4: Between s1 and s2	
		Macro	Micro	Macro	Micro	Macro	Micro	Macro	Micro
C4	F-statistic	2.258	87.284	3.828	241.302	1.619	7.270	.794	7.072
	p-value	.108	0	.061	0	.227	.065	.391	.008
C5	F-statistic	2.375	50.428	6.896	115.794	.502	13.376	.149	14.342
	p-value	.095	0	.014	0	.492	.0003	.707	.0002
C6	F-statistic	4.918	23.294	1.769	45.102	10.251	10.498	1.336	8.805
	p-value	.008	0	.195	0	.008	.002	.270	.004

Spectrogram of Vibrato Removal

Conclusions

Goal 1: Understand spectral content's impact on timbre

- Visualization of the spectral content of harmonics and inharmonics demonstrates differences exist in their timbre content
- Logical series of four ANOVA tests provided evidence that the inharmonic content contributes the most in terms of the timbral differences between acoustic violins and synthesizers
- Experimental results support musical literature concerning synthesizers which could not easily replicate the timbre of a string instrument due to its inharmonics (Berg and Stork). However, the results disagree with beliefs that timbral differences arise from harmonic content (Smith)

Goal 2: Remove synthesizer's vibrato to enhance timbre

- Best results obtained utilized a simple yet quite elegant method by adjusting the spectral amplitudes near the harmonics of the tone
- Modified spectral components were subsequently converted back to the time-domain WAV audio signals
- Listening tests of the modified WAV audio and visualization of its corresponding spectrogram provided further evidence of successful removal of the vibrato

Future Work

- Continue to develop the tool for young violinists to analyze richness of spectral content before buying their first instruments
- Develop features to examine the quality of sounds attributed to acoustic violins and bows by isolating them

References

Berg, R. E., & Stork, D. G. (2005). *The Physics of Sound.*

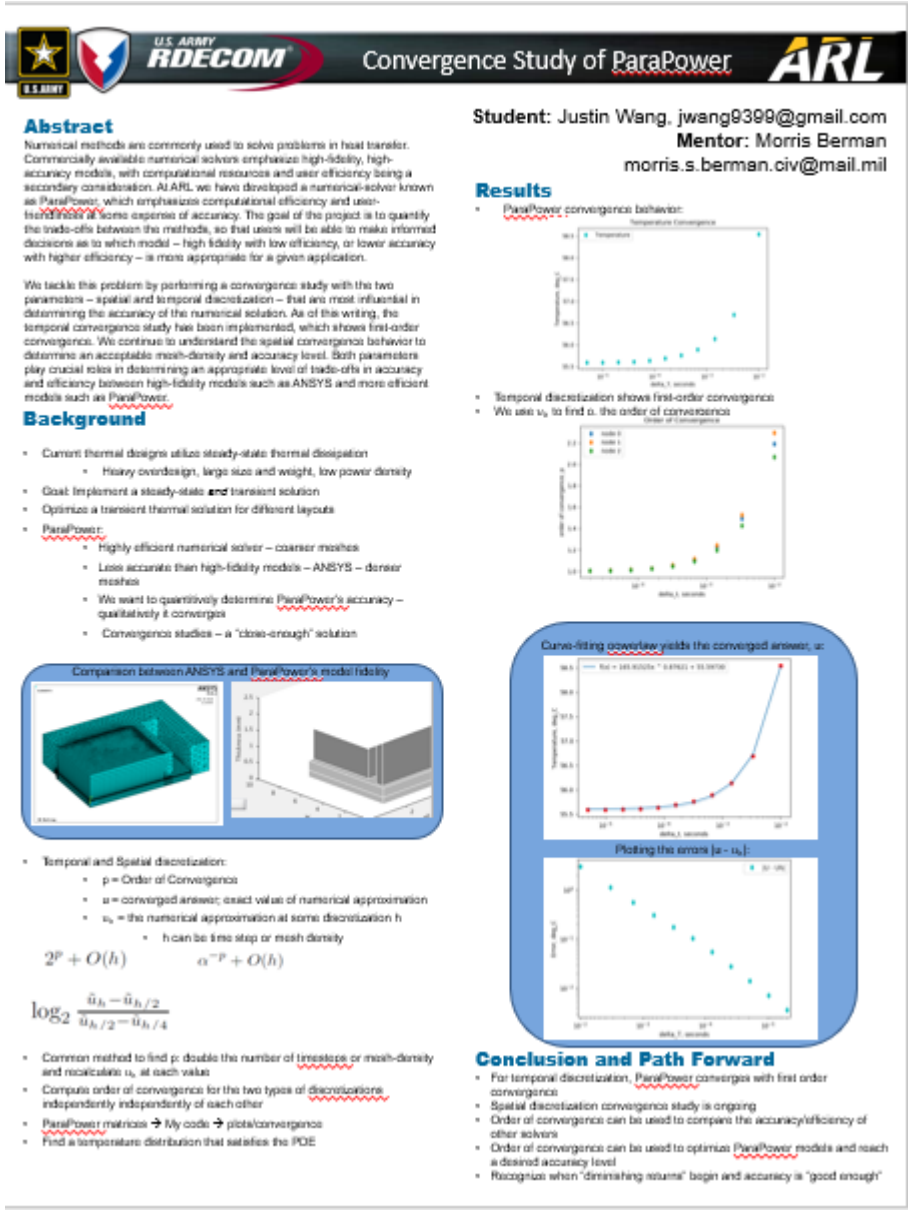
Oliphant, T. E. (2007). Python for Scientific Computing.

Downey, A. (2014). *ThinkDSP: Digital Signal Processing in Python.*

Smith, S. W. (1997-2011). *The Scientist and Engineer's Guide to Digital Signal Processing.*

Back to ARL again – summer of 2018

- Concerned about congressional budget; glad to be back
- Worked on a project developing a self-cooling chip
- Used last summer's shock-and-vibration toolbox efforts to simplify data handling this summer
- My contribution: convergence study of heat transfer from temporal and spatial perspectives
- Have learned tremendously, again



U.S. ARMY RDECOM

Convergence Study of ParaPower

ARL

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Abstract

Numerical methods are commonly used to solve problems in heat transfer. Commercially available numerical solvers emphasize high-fidelity, high-accuracy models, with computational resources and user efficiency being a secondary consideration. At ARL we have developed a numerical-solver known as ParaPower, which emphasizes computational efficiency and user-friendliness at some expense of accuracy. The goal of this project is to quantify the trade-offs between the methods, so that users will be able to make informed decisions as to which model – high fidelity with low efficiency, or lower accuracy with higher efficiency – is more appropriate for a given application.

We tackle this problem by performing a convergence study with the two parameters – spatial and temporal discretization – that are most influential in determining the accuracy of the numerical solution. As of this writing, the temporal convergence study has been implemented, which shows first-order convergence. We continue to understand the spatial convergence behavior to determine an acceptable mesh-density and accuracy level. Both parameters play crucial roles in determining an appropriate level of trade-offs in accuracy and efficiency between high-fidelity models such as ANSYS and more efficient models such as ParaPower.

Background

- Current thermal designs utilize steady-state thermal dissipation
  - Heavy overdesign, large size and weight, low power density
- Goal: Implement a steady-state **and** transient solution
- Optimize a transient thermal solution for different layouts
- ParaPower:
  - Highly efficient numerical solver – coarser meshes
  - Less accurate than high-fidelity models – ANSYS – denser meshes
  - We want to quantitively determine ParaPower's accuracy – qualitatively it converges
  - Convergence studies – a "close-enough" solution

Comparison between ANSYS and ParaPower's model fidelity

- Temporal and Spatial discretization:
  - p = Order of Convergence
  - α = converged answer; exact value of numerical approximation
  - u_h = the numerical approximation at some discretization h
    - h can be time step or mesh density

$$2^p + O(h) \qquad \alpha^{-p} + O(h)$$

$$\log_2 \frac{\hat{u}_h - \hat{u}_{h/2}}{\hat{u}_{h/2} - \hat{u}_{h/4}}$$

- Common method to find p: double the number of timesteps or mesh-density and recalculate u_h at each value
- Compute order of convergence for the two types of discretizations independently independently of each other
- ParaPower matrices → My code → plots/convergence
- Find a temperature distribution that satisfies the PDE

Results

- ParaPower convergence behavior:

- Temporal discretization shows first-order convergence
- We use u_h to find α, the order of convergence

Curve-fitting powerlaw yields the converged answer, α:

Plotting the errors $|\alpha - u_h|$:

Conclusion and Path Forward

- For temporal discretization, ParaPower converges with first order convergence
- Spatial discretization convergence study is ongoing
- Order of convergence can be used to compare the accuracy/efficiency of other solvers
- Order of convergence can be used to optimize ParaPower models and reach a desired accuracy level
- Recognize when "diminishing returns" begin and accuracy is "good enough"

Reflection – 16 weeks of internship at ARL

- No better way to spend the two summers
  - Sense of responsibility
  - Use of public transportation!
  - Improve my technical skills
  - Meet other like-minded high schoolers, undergraduates, and graduate students
  - Clear my doubt regarding “instrumentation error”
  - **Meaningfully contributed to my mentor’s project**
- Solidify my selection of an engineering career
  - Engineering physics or electrical engineering

Reflection – 16 weeks of internship at ARL

- Remove any doubt whether math and physics are essential
  - See how they are used in a real lab
  - Use of instrumentation
  - Math modeling & model comparison
  - Heat transfer and phase change materials
  - Data processing and programming
  - Use of HPC systems – HPCMP ORS
- I really like the staff at ARL
  - They treated me like I am one of them
  - Hope to come back to intern for four more summers while in college

Reflection – DoD-sponsored JSHS competitions

- Competition format encourages communication
  - Written & oral
  - Judges are college professors or experts in the judging field
- Competition categories
  - Environmental, biomedical, life, medicine, engineering, math & computer, physics, chemistry
- Great to see so many like-minded future scientists
- Speakers and panelists for the National JSHS were fantastic
- Toured many DoD facilities

Where can I go from here – back to school

- None of the above could be possible without
  - AEOP: SEAP & JSHS & **ARL**
  - Time and energy my mentor spent on me
  - ARL colleagues' open arms & great projects
  - Countless people from ARL and AEOP
- 8-week is really too short
  - Getting momentum to contribute around week 6
  - Almost time to wrap up!
  - But I have not finished the assignment yet
  - May I stay a bit longer?

Extending beyond an 8-week apprenticeship

- Recalled past conversations with students who participated in science competitions
  - I explored a very simple idea of my own
  - Many other students continue investigations from larger projects originated from government or university research labs
- Is it possible to extend duration of the internship beyond summer?
  - Benefit of the mentor's project and the apprentice
  - Guest researcher?

Parting words

- SEAP and JSHS opened my eyes to the world of STEM lab career
- ARL has changed my future prospect
- Grateful for my ARL mentor-and-colleagues' guidance and support
- Hope to participate in 2019 DoD-JSHS competition
- Look forward to coming back to ARL for college internships:
  - DoD's SMART Scholarship for Service Program
  - AEOP's URAP
  - AEOP's CQL
- I plan to be back to present a technical topic at a future Army S & T Symposium & Showcase!

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