Multidisciplinary Undergraduate Research Project to Create Musical Effect Box

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Abstract

This paper reports on a team of undergraduate students in Electrical Engineering Technology and Music and Arts Technology. The students developed a protype musical effects module utilizing real-time digital signal processing. The students defined the effects, selected a DSP development platform, designed a user interface. As a team, they created programs using applications from both the music and engineering technology curriculums. By leveraging tools from Lean Six-Sigma DMADV process (Define, Measure, Analyze, Design, Verify) the students were able to go from concept to prototype in seven weeks.

Background and Introduction

The inception of this project was with an Electrical Engineering Technology student who supports himself as a disk jockey (D.J.) His music was stored and controlled by a laptop. This had several drawbacks. First, he had to stay at the table with the laptop to start or mix any music; he wanted to have options to control the music with a hand-held device, like a smart phone. Another concern was the vagaries of the PC operating system: if the computer needed to re-boot, or had other problems with software, the music would stop. Since PCs often have system issues, this would regularly embarrass him during a job. Another desirable was to combine functionality of several programs into one system. The student wanted to add a variety of effects to the music, as well as control playback (stop, start, volume).
In consultation with faculty, the student determined a real-time DSP system with supporting storage, I/O and user interface would be a good platform for the new system. Although the student's final goal was a replacement D.J. system for his laptop, his faculty mentor broke the project into smaller goals. The first of these was to determine optimal hardware and operating system for the new system.

In order not to limit possibilities to those solutions already known to the faculty and student, they recognized the need for a team to research the solutions. IUPUI has a Multidisciplinary Undergraduate Research Initiative (MURI). According to the MURI website (https://crl.iupui.edu/crlprograms/facultyprograms/muriprojectawards/index.html):

> MURI facilitates the creation and support of multidisciplinary research teams consisting of undergraduate students, graduate students, post-docs, senior staff, and faculty. Projects should represent two or more disciplines and should offer undergraduate students the opportunity to engage in a substantive research experience focused on a significant

research problem. This is a unique opportunity provided to IUPUI faculty and researchers for mentoring students while conducting pilot projects or testing new techniques and designs. Students receive a $1,000 (academic year) or $3,200 (summer) research stipend. The mentors will receive up to $2,000 for research supplies or equipment. MURI is funded through a partnership between the Center for Research and Learning and the School of Engineering and Technology.

The Purdue School of Engineering and Technology at IUPUI has unique breadth of departments and programs. Included are the departments of Engineering Technology (ET), Music and Arts Technology (MAT), and Technology Leadership and Communication (TLC). Two faculty members from ET and MAT proposed the project to the MURI program, and the project was approved for the summer of 2018. The team for this project draws on faculty and students from several of the school's disciplines:
- o Electrical Engineering Technology: one faculty member and two undergraduate students. Both EET students had interest and experience in audio.
- o Music and Arts Technology: one faculty member, one graduate student, and two undergraduate students. Both MAT undergraduate students were pursuing computer science minors.
- o Technology Leadership and Communication: one graduate student

The goals for this project were twofold: to design and configure a real-time DSP platform for the music effects system and to provide an experiential learning environment where students could apply best practices in engineering design. The students concentrated on the technical goals:
- Choose a few common D.J. music effects to focus upon and develop algorithms for the effects
- Select a real-time Digital Signal Processing (DSP) platform to implement the effects. (Three sample evaluation boards were purchased before the beginning of the summer for the students to test, but in the end, none of these were used. The students found a better solution.)
- Develop and implement a user interface for the effects system

Although the students were focused on completing the project, the faculty were anxious that the students learn and demonstrate professionalism skills, such as those stated in the ABET-ETAC student outcomes (http://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-technology-programs-2018-2019/#GC3):
- (e) an ability to function effectively as a member or leader on a technical team;
- (f) an ability to identify, analyze, and solve broadly-defined engineering technology problems;
- (g) an ability to apply written, oral, and graphical communication in both technical and non-technical environments; and an ability to identify and use appropriate technical literature;
- (h) an understanding of the need for and an ability to engage in self-directed continuing professional development;
- (i) an understanding of and a commitment to address professional and ethical responsibilities including a respect for diversity;
- (j) a knowledge of the impact of engineering technology solutions in a societal and global context; and
- (k) a commitment to quality, timeliness, and continuous improvement.

To achieve all of these goals, both technical and professional, the faculty determined to bring together students and faculty with diverse backgrounds and interests, and utilize the DMADV (Define, Measure, Analysis, Design, Validate) design for Lean Six-Sigma process.

Process

Student Team Members

Michael Bauchert is a Music Technology major with a minor in Computer Science. His recent work is in compositional applications of web audio, but he's done everything from video production to producing and recording bands. Michael prototyped the effect using Max MSP and worked with Collin in design and writing the final program on the TI board.

Kacie Darrough is a sophomore full-time Electrical Engineering Technology student at IUPUI. Her summer MURI role was to do research about the ADAU1761Z evaluation board, as well as testing it. She also worked with the Arduino Mega and a TFT touch shield to create a user interface and research serial communication.

Figure 1 From left, Professor Elaine Cooney, with Michael Bauchert, Colin Eades, Kaci Darrough, and Alex Perr working in the Engineering Lab on the project.

Collin Eades is a sophomore Music Technology major minoring in computer science. He is involved in music composition, studio engineering, and performance around the local Indianapolis area. Collin wrote a large portion of the program that runs the device created and came up with several of the design concepts that were used in the device."

Alex Perr is a senior Electrical Engineering Technology student. An active DJ and computer musician, Alex originally proposed the idea that became the MURI project. He is utilizing the hardware platform developed as the foundation of his senior project.

Design Process

To guide them through the design process, the MURI team used a six-sigma methodology that focus on the development of a new product. The method's five phases – Define, Measure, Analyze, Design, and Verify (DMADV) - are examined below:

Define
The define phase focuses on identifying the purpose, features, and functionality of the project. Once these three items are identified, the team was able to set goals and measurable for the summer. The team used a SIPOC (supply, input, process, output, customer) map to assist with summarizing the desired inputs and outputs of the system (see Table 1). Once complete, the team was able to compile a list of objectives for the project.

Supply	Input	Process	Output	Customer
.mp3	USB	filter	RCA	DJs
.wav	XLR	modulate	XLR	musicians
live audio	RCA	effects	3.5 mm	audio engineers
	3.5 mm		1/4 in	
	1/4 in		.mp3	
			.wav	

Table 1 - SIPOC

Measure
The measure phase focuses on the creation of specifications that allow for the product's functionality to be measured. Requirements that are critical to quality (CTQ) were determined using the results of the define phase and a measurement plan was put together to allow for data collection and future analysis of the CTQ elements.

Analysis
The analysis phase focuses on analyzing the data from the measure phase to determine if improvements or adjustments are required in the product. The team used development boards to construct three prototypes of their effects box. The systems were tested according to the measurement plan and the highest performing system was selected.

Design
The design phase focuses on the development of both high level and low-level designs. With each modification to the selected design, the team had to repeat the analysis phase to ensure it met or exceeded the original specifications. The team designed a customer survey to conduct usability testing on the user interfaces. The user's tested two displays (Display A and Display B) and compared them based on four criterion. The higher rated display was implemented in the final design.

	User 1	User 2	User 3	User 4
Looks	A	A	A/B	A
Performance	A	A	A	A
Meets Expectations	B	A	B	B
Final Preference	A	A	B	A

Table 2 - Usability Testing

Verify
The verify phase focuses on ensuring the final design meets end user's requirements. To ensure the final design met project requirements, the team demoed the product to the faculty leads. The final project exceeded the original expectations of the faculty.

Results

Software

The MURI Team designed a portable DSP device inspired by FL Studio's Gross Beat, a third party VST plugin for musical usage in Digital Audio Workstations (DAWs). The portable device was designed by utilizing C language in order to create a time-based audio effect. In real time, the device ("The Time Machine") manipulates the playback rate and looping of audio stored in a buffer. The best hardware options were chosen from what was available
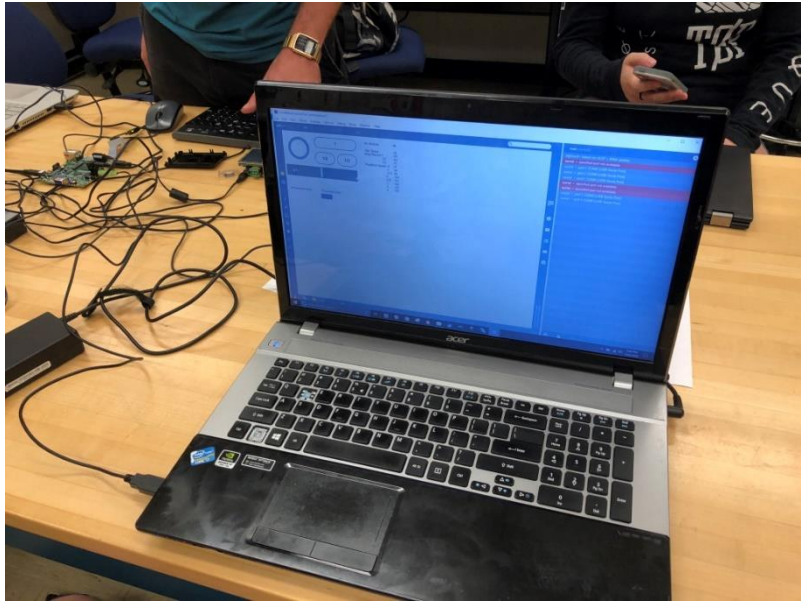

Figure 2 A computer used for algorithm development.

and a functioning program was created to implement the design. While the team had to make several compromises on hardware choice and software design, the project ultimately demonstrated a successful path to creating an audio effect module.

Max MSP and Jitter is a programming environment used primarily by musicians, but is also useful for video manipulation. Its design is object oriented, allowing musicians and programmers who are music lovers to create applications for customized use in music creation, production, and performance. Max, also known as Max/MSP/Jitter, is a visual programming environment for music and multimedia developed and maintained by Cycling '74. Its design is object oriented, allowing musicians and programmers who are music lovers to create applications for customized use in music creation, production, and performance. Created by Miller Puckett in 1988 at the Institut de Recherche et Coordination Acoustique Musique (IRCAM), it has been used by composers, performers, software designers, researchers, and artists to create recordings, performances, and installations.[1] The Max program is modular, utilizing shared libraries that can be jointly connected. Max has a large user base of programmers unaffiliated with Cycling '74 who enhance the software with commercial and non-commercial extensions to the program. Due to its ability to allow musicians to create virtually any audio process, it is the most widely used music program in the world today, harnessed by industry, academia, composers, performers, and producers. [2]

Hardware

The DSP chip selected to implement "The Time Machine" is the TI OMAP-L138. It has an ARM9 processor + C6748 DSP. The ARM allows for flexible control of the C6748 DSP. The OMAP-L138 Low Cost Development Kit (LCDK) was used to develop and test the system. The LCDK comes equipped with all of the necessary hardware connectors needed, such as 3.5mm audio jacks, USB UART connectors, and serial connectors. The LCDK comes equipped with a 128 MB of SDRAM, which allowed for a large buffer size. This was used to create a maximum buffer size of 16,777,216 samples, which afforded an audio delay of 350 seconds. The LCDK is equipped with an audio codec that has a variable AD/DA conversion resolution of 8-32 bits. Code was developed in C programming language on Texas Instruments' Code Composer Studio IDE.
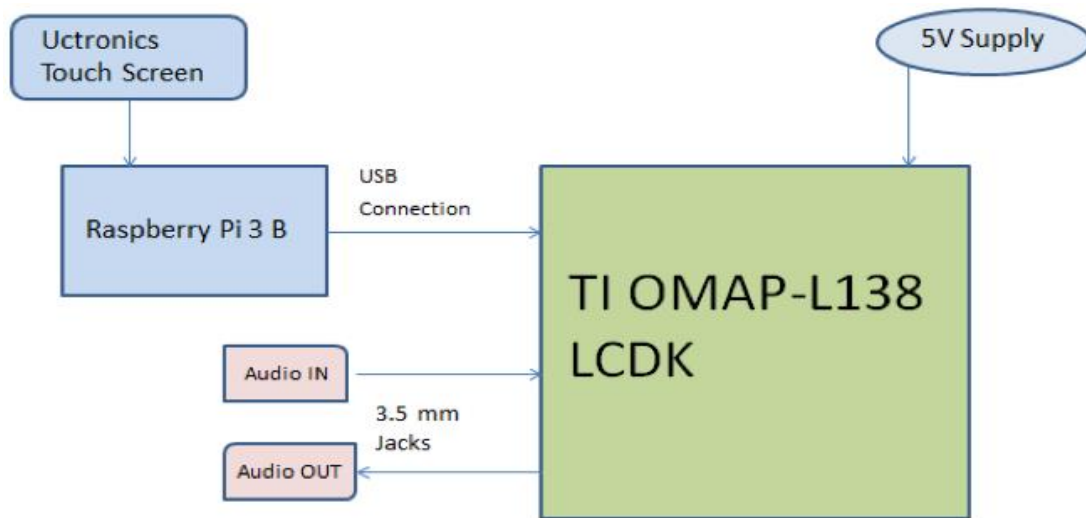

Figure 3 System Block Diagram

Interface

The Raspberry Pi 3 model B used for the graphical user interface (GUI). This model supports a Quad Cortex A53 CPU @ 1.3GHZ and 1 GB of SDRAM which is equipped with HDMI ports, USB Hosts, Serial connectors, and GPIO. The USB host used to communicate and send commands to the OMAP-L138 LCDK. The 3.5inch LCD touch screen made by Uctronics placed on the top of Raspberry Pi for the GUI. The program on Pi sends serial data via USB to the TI OMAP. The on-board audio codec TI AIC3106 converts an analog audio signal into a digital signal which gets manipulated by OMAP processor. The OMAP-L138 LCDK is powered by a 5V DC power supply which also powers the with a micro USB. See Figure 1 System Block Diagram for the configuration of the interface with the LCDK.
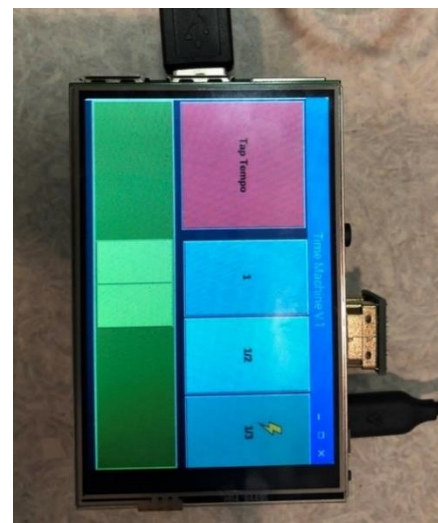

Figure 4 : Interface for the Time Machine device

Operation

A software is written for the OMAP in C using Texas Instrument's Code Composer Studio. It initializes the audio codec, the DSP and to receive commands form Pi via USB UART. Codec stires the digital audio at a buffer rate of 48 Khz which is also the sampling rate. The change in buffer size depends upon the BPM (beats per minute) of the song which is determined by the Tap Tempo function. The 2x speed function works by going back into previous data buffer and speeding up for one bar length. The ½ speed works by playing back information stored in the buffer at ½ bar length. The reverse function works by reversing the playback direction.

Team Building

Due to the dynamics of the project team, conflict between team members was inevitable. During the early phases of the project the team meetings would deteriorate from discussion to disagreement over the direction of the project and desired features. Reasons for this early conflict stem from three problem areas: lack of trust between team members, no clear vision of final project, and no clearly defined leader. Since the team members were from various majors, they did not understand the strengths and weaknesses of each member leading to a level of distrust about the abilities of other members. As the project moved forward, members would have to gain each other's trust by demonstrating their own ideas of how best to implement features. After a few meetings, the trust between members and confidence of each member had increased allowing for better collaboration of ideas. At this point, the vision of the final project stated to become clear with well-defined features and functionality. Although the team never developed a single leader, it operated with a dual leadership format with one member taking over the hardware integration and the other member taking over the software functionality. Collaboration between these two members was key in the integration of the separate components into a single working prototype. This project provided a real-world learning experience for the team members on the inner workings of a project team. The team was able to effectively work through conflict, resource management, changing deadlines, and technical problems to provide a high quality finished product that exceeded the end user's expectations.

Problem Solving

During the design process, the team encountered several technical issues in route to a finished product. To overcome these issues, the team utilized several techniques to obtain the needed assistance. The team searched through technical documentation provided by the manufacturer or discussion boards to work through some issues. For more complicated issues, the team made calls to the manufacturer's technical support group or utilized the knowledge and expertise of professors on campus. Using all of the techniques above, the team was able to navigate through several technical complications while also meeting their project timelines.

Student Observations

The students recognized the process and the technical success of the project. Mr. Bauchert states:

"Our team designed a mobile DSP device inspired by Gross Beat, by utilizing C language in order to create a time-based audio effect. In real time, the device manipulates the playback rate and looping of audio stored in a buffer. Our team compared four DSP development boards to find the one best suited to host the program. We designed a touch-screen user interface to control the program and compared two different microcontrollers to host this interface. The best
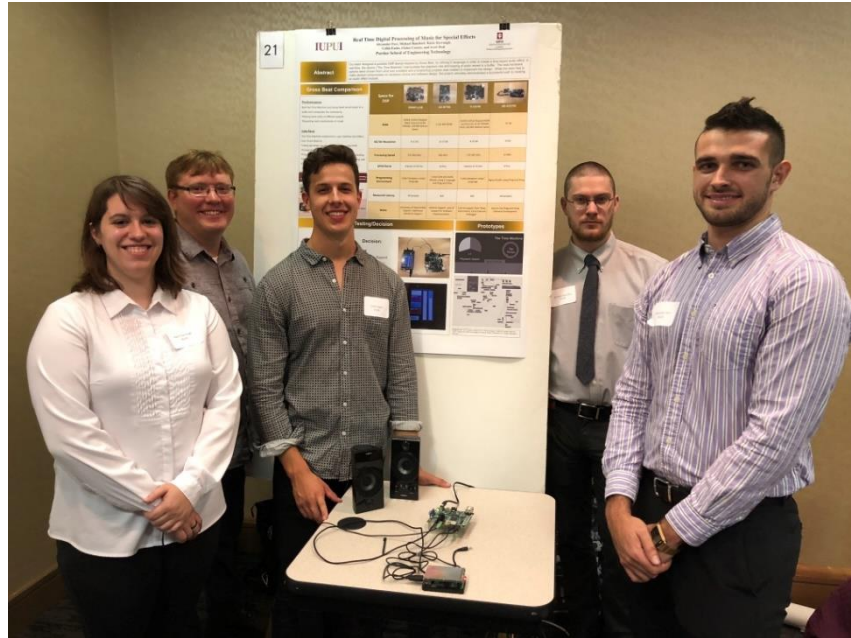

Figure 5 Team presenting their work at the IUPUI MURI Presentations Day. From left, Kaci Darrough, Andrew McNeely, Colin Eades, Michael Bauchert, and Alex Perr.

hardware options were chosen from what was available and a functioning program was created to implement the design. While the team had to make several compromises on hardware choice and software design, the project ultimately demonstrated a successful path to creating an audio effect module."

Conclusions

The MURI team successfully designed a music effects box by utilizing real-time digital signal processing and a touchscreen interface into a single system. The system is optimized for time-based effects, such as loop back and playback rate. The touchscreen hosts a GUI to allow for effect selection and setting the desired tempo. The hardware platform is currently being adopted as an advanced system with more complex features. In the new version, the user will able to program a set of hardware buttons with a variety of different time-based effects using the touchscreen GUI. It further gives a list of different effects that can be applied to the buttons. Finally, it will implement a knob to change the tempo of the effect instead of Tap Tempo option utilized in the current version.

Besides the technical success of the design, the team of undergraduate students, graduate students and faculty demonstrated the effectiveness of multidisciplinary research including all aspects of STEAM. The students demonstrated professionalism, communication, and project management to creatively and successfully solve a problem.

References

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Biographical Information

ELAINE COONEY is a professor and program director for Electrical Engineering Technology in the Purdue School of Engineering and Technology at IUPUI. She is a Senior IDEAL Scholar with ABET, which means that she presents assessment workshops with other Senior IDEAL Scholars. Cooney performs with the IUPUI University Choir and IUPUI Singers. She is a member of the Tavel Center.

SCOTT DEAL is a performer, composer and media artist who engages new works of computer interactivity, networked systems, electronics and percussion and is a professor of Music and Arts Technology at IUPUI. He has numerous recordings, including his recording of John Luther Adams' Four Thousand Holes, that was listed in New Yorker Magazine's 2011 Top Ten Classical Picks. Deal is director of The Donald Louis Tavel Arts and Technology Research Center.

ANDREW MCNEELY is a graduate assistant in the Electrical Engineering Technology department of the Purdue School of Engineering and Technology at IUPUI. He teaches 100 level courses in circuit analysis methods and engineering principles while researching methods to better incorporate technology into curriculum. His Bachelor's degree is in Electrical Engineering Technology from IUPUI and he is currently pursuing a MS in Technology with an emphasis in technical communications from IUPUI.

HARRY CHAUBEY is a Ph.D. student in the Music Arts Technology Department at IUPUI and is a graduate research assistant for the Tavel® Lab. After earning his master's degree in Music Technology at Trinity UCD Ireland, he carried out design and DSP work for PatchBlocks®, a U.K.-based synthesizer company. His areas of interest are micro-controller based standalone devices working on real time DSP algorithms, sound manipulation, DIY sound devices using hardware hacking and embedded systems.