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Laser Music - Authentic Engineering Product Development for a Real Customer

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Laser Music – Authentic Engineering Product Development for a Real Customer

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The Raritan Valley Community College (RVCC) Engineering program "Authentic Engineering Experience" course tasked a Team of four Engineering students to design, prototype, build, and deliver a real product to a real customer. The product was a laser-music system that uses only modulated laser-light to transmit music across a room to multiple receivers with audio-speakers. The objective of the course was to expose students early in their academic careers and under "authentic engineering" conditions, to vital skills and practices used daily in industry. A secondary goal was to give students product development and project execution experience to relate to potential internship and professional employers.

I. Introduction

During the Fall 2016 semester, four Raritan Valley Community College (RVCC) Engineering students participated in an Engineering and Music-Arts collaboration as part of a hands-on "Authentic Engineering Experience" course to design, prototype, build, and deliver a real product for a real customer.

The Engineering Student Team was tasked by the Customer, a RVCC Music Professor (and co-author Strong), to build a laser-music product that uses only modulated laser-light to transmit music across a room to multiple receivers with audio-speakers. The Customer did not provide guidance to the Engineering Team regarding preferred methods to achieve the product performance goals. It was an authentic open-ended product development project.

The team converged on a product solution using two micro-computer controlled lasers mounted on a team-built servo-motor platform that projected laser beams to team-built optical-detectors mounted on six independent audio speakers positioned around a performance room. An input audio signal modulated the laser light using a team-built circuit. The Customer and Engineering Team members composed the sequence and timing of the lasers to activate the speakers. The team-members conducted the programming, testing, and debugging. The effect was to fill the performance room with music emanating from different locations and in time with the composition to "shape" the music within the room for a unique audience experience. A debut laser-music concert was given by the student team December 7, 2016 and included students, faculty, staff, and the RVCC President in attendance and featured Handel's Halleluiah Chorus.

Throughout the project, the team members were exposed to important practical skills typically learned later when in industry. The team members were treated and worked as professional Engineers. Although guided by industry-experienced staff, the overwhelming emphasis was for the student Team to reach their own designs, experience their own failures and successes in earning their own know-how, resolve their own communications and scheduling conflicts, and to respond to customer critical comments on performance. The goal was to give students authentic hands-on product development and project execution experience to relate to potential internship and professional employers.

The spirit of this project is in line with previous successful efforts to expose students to "authentic" engineering experiences and environments through, for example, Service Learning [1], Learning Factories [2], Capstone Projects [3], hands-on 1st-Year Engineering Courses, Learning in Laboratory Settings [4], and Engineering courses featuring Mechanical Dissection as a learning tool [5].

The current "Illuminated Umbrella" project is a continuation of the pilot "Authentic Engineering Experience" course initiated at RVCC in 2015 [6] and is one of two projects presented at this conference [7].

I. Industry Skills Focus:

During the project the student-professor relationship was suspended and replaced by a professional engineering team – manager relationship. The scenario was that the student team were employees of an engineering company that makes novel technical products for specific customers. All project activity was hands-on and "live" – without classroom lectures or Labs. Principles and skills were experienced first-hand. The focus was for the student team to learn by doing. Concepts and skills emphasized were those directly useful for engineers in a professional/industry environment and included:

- Focus on the Customer - Communicate with the customer, understand the customer's needs, and negotiate achievable needs, conduct interim demonstrations, collaborate with the customer, and deliver the product on-time.
- "Do what you say you will do" – Teamwork, division of labor, project planning, task execution, leadership, and responsibility.
- Engineering Prototyping – Idea generation, start simple then improve, face high-risk problems first, think through each step in-detail to reduce risk
- Grit and Determination – Anything that can go wrong will go wrong – push through.

II. Voice-of-the-Customer

The Engineering Team consisted of four RVCC Engineering students. The Team was not informed of any of the details of the project – not even the type of product to be made. The project started on the first day of the semester, September 2, 2016, with a meeting with the Customer to learn the details of the product request and specifications.

The Customer requested a laser-music product that uses only modulated laser-light to transmit music across a room to six optical receivers with audio-speakers. The customer did not indicate or suggest how to achieve the required product performance – those decisions were left entirely to the student Team.

III. Idea Generation and Exploration

In response, the Engineering Team conducted a brainstorming session to generate ideas to address the Customer's requested product. The brainstorming used standard rules where each team-member sequentially gave one idea and where all ideas were listed without discussion or critique. The idea was to generate as many specific and open-ended ideas as possible. The result was a large list of ideas that covered a broad spectrum of possible technologies and solutions. The Engineering Team recognized that they needed to learn more about many of the ideas before decisions could be made as to which sub-set of technologies or approaches would likely be the more effective. The ideas were roughly grouped into categories that would later form the main areas of engineering work for executing the project, including the laser modulation circuit, laser mount and servo-motors, microcontroller, programming, optical receiver, audio amplifier and speaker, and mechanical supports. The Engineering Team members each accepted to research a set of the brainstorm ideas. At the next meeting the team-members reported back using 3-5 minute presentations per key topic to efficiently inform the Team with the objective to reduce the technology options to a few testable technologies.

IV. Technology Selection and Prototyping - 1st Customer Demonstration

The Engineering Team members divided the responsibility to focus on the main technology areas to make progress in parallel. Co-authors Rokosky and Donlan focused on laser modulation circuit, laser mount and servo-motors, micro-controller, Rodriguez developed expertise at programming the microcontroller, and Rickman was responsible for developing the optical receiver system and system mechanical supports.

An initial project plan was developed to coordinate the Team's work tasks. A Team Leader was chosen from the Engineering Team members on a weekly basis to maintain the schedule, communicate within the Team to ensure all members stayed on schedule, identify technical and schedule problems during the week, and maintain and communicate a parts-order list. The Engineering Team and the "company" manager (co-author Stupak) met a minimum of once per week to review progress. The Engineering Team members were expected to invest at least six professional-engineering hours towards the project weekly. The first Customer prototype demonstration meeting was defined for November 1, 2016.

V. Laser Modulation Circuit

The Engineering Team's first challenge was to create a circuit that would superimpose an audio signal onto the laser circuit to cause the brightness of the laser to vary in time and intensity per the rhythm and volume of the music. This challenge was greater because none of the Team members were well versed in electronics and had not even completed an introductory Circuits course. The approach was to begin with the simplest circuit possible so that the Team could understand the function of the circuit and increase the complexity as required.

The laser modulation circuit consisted of a variable voltage power supply, an AM/FM radio with an audio-output port, and a laser pointer. The concept of the circuit function was that the music from the radio output was a signal of varying voltage. The radio output voltage was superimposed onto the steady voltage powering the laser pointer. The varying radio output voltage caused the laser pointer light-beam to vary in intensity. The varying intensity of the laser light-beam was received by a solar cell which, by the photoelectric effect, generated a current that was amplified in a small audio speaker where the music was emitted at a position across the room (Fig. 1).

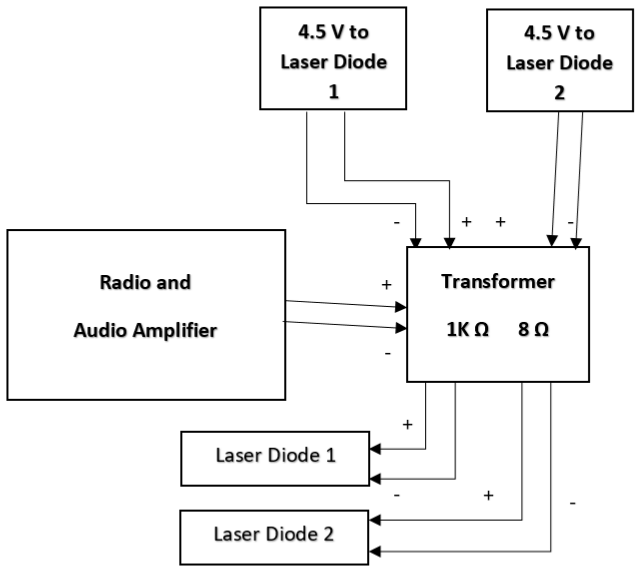

Figure 1. A schematic of the laser modulation circuit showing the radio and audio output, the laser-pointer circuit, the superimposed laser-pointer light-beam.

A practical lesson learned during this first phase was the importance of testing electrical connections. Faulty connections, especially for wire conductivity in the electrical bread-boards led to many instances of falsely concluding that there was a component problem when it was a simple connectivity problem.

A technical lesson learned during this first phase was that a stronger input audio signal resulted in greater laser modulation and output signal received and corresponding loudness of the sound. This observation was essential in the planning of the system because the customer requested a robust, powerful sound from each speaker. It was reasoned that the best way to boost pre-laser audio strength was to employ an amplifier directly after the audio gets introduced into the circuit.

Another unexpected issue was that the laser pointer lifetime was very short in some cases. After the premature end of a number of laser pointers, it was found that the power supply being used did not regulate the voltage properly between voltage settings; leading to voltage spikes and over-voltage that was damaging the laser pointers. A careful discipline of verifying the supply voltage and current was implemented to minimize the over-voltage possibility before testing the system.

VI. Laser Mounting, Motors, and Microcontroller

The Customer requested that only two lasers could be used and that the lasers must automatically point to the appropriate optical receiver and speaker location. Since six speakers were required, each of the two lasers would point at three receivers and speakers. While the movement of the laser would be accomplished by the rotation of a servo-motor, the Engineering Team was concerned that too much time would be required to move the laser light-beam from one speaker to another resulting in brief but uncomfortable periods of silence during a performance of the product (e.g., 60 degrees in 0.23s).

The Team brainstormed that mirrors could be employed to take advantage of the reflection of the laser light-beam to reduce the laser rotation angle and time. It was originally thought that the best option was to direct the laser light-beam to mirrors positioned on the performance-room wall half-way between the outer receivers to reflect the light to the optical receivers and reduce the laser rotation angle by 50%. However, using ray-tracing diagrams, the Team showed that a better option was to place two angled mirrors on either side of the central receiver/speaker for each of the two lasers so that the motor rotation could be reduced to only a few degrees (Fig. 2).

A small, credit-card sized microcontroller computer called "Raspberry Pi" was selected to power the servo motors and direct the lasers. The Raspberry Pi, complete with a Python computer programming library, enabled the lasers to be programmed to move to the exact direction needed. However, the Raspberry Pi microcontroller is not specifically made to drive servo motors and an uncontrolled variation on the motor position was discovered and later eliminated with the addition of a commercial component purpose-made for this correction (Fig. 3).

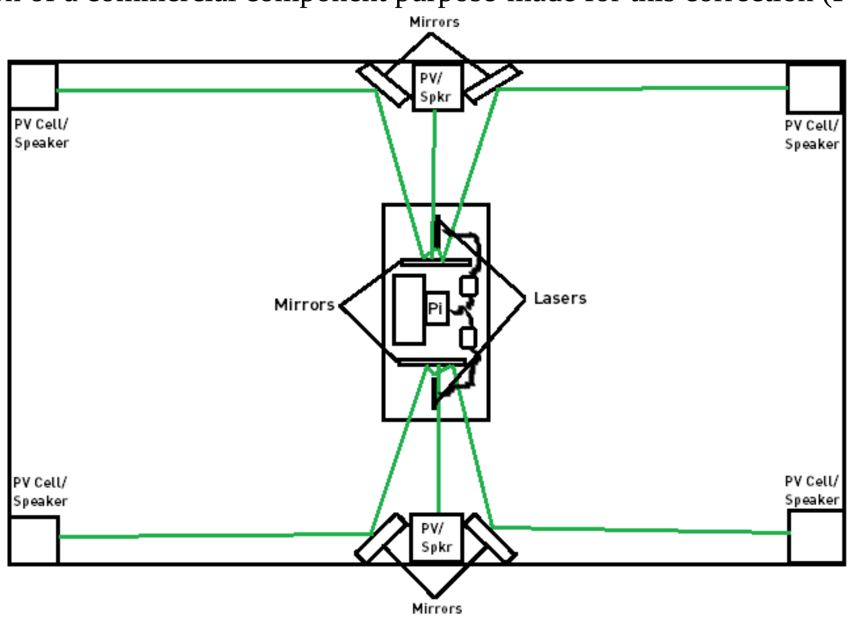

Figure 2. A bird's-eye-view schematic of the Laser-Music product layout, including the central position of the programmable and rotatable laser pointer and Microcontroller (Pi), the angled reflecting mirrors on 5ft stands, and the optical receivers (PV cells), audio amplifiers and speakers on 5ft moveable stands. The red ray-tracing illustrates the laser light beam directions.

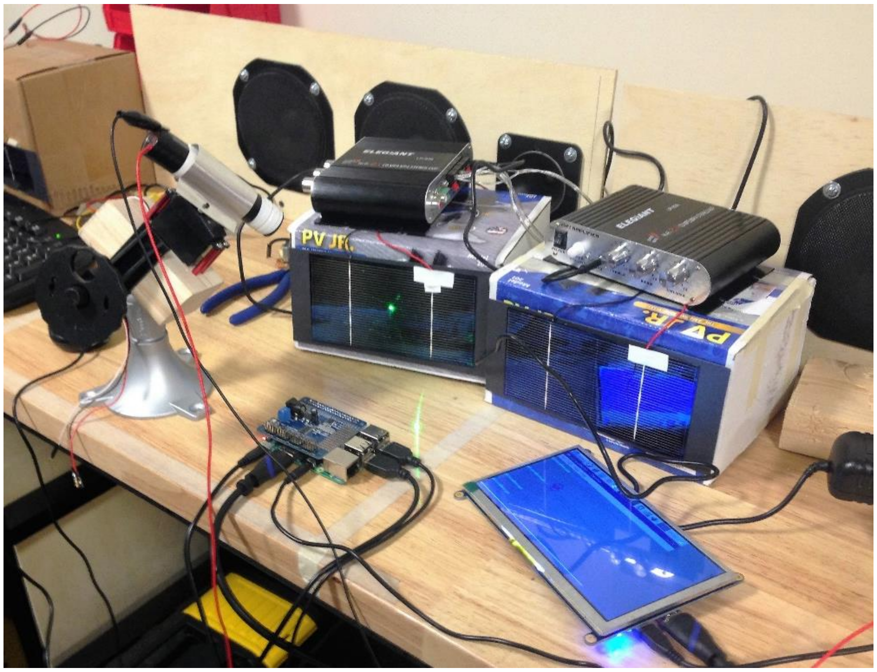

Figure 3. The prototype Laser-Music product featuring the laser-pointer mounted on the servo motor and held in an adjustable vise (left), Raspberry Pi microcontroller (center left), two photovoltaic cells attached to boxes with audio amplifiers on top, (center-upper right), and early-version speakers (background).

VII. Programming

The programming of the Raspberry Pi microcontroller was also a challenge as the system and the Python programming language was new to the Engineering Team. But with dedication and persistence the Team learned to program the microcontroller to control the angle the motor would move and the length of time the laser would remain pointed at a given optical receiver. An advantage of the code was the ability to cut-and-paste code of repeating commands, for example a given laser rotation angle, and simply adjust the time parameter for the new part of the music. Two difficulties of the programming were matching the movements of the laser to the beat and rhythm of the music and to make the program start at the exact moment the music started. The former problem was solved with experience and later working directly with the Customer and the latter problem was solved by adding a line of code that synchronized the program start with the start of the music.

VIII. Optical Receivers, Amplifiers, and Audio Speakers

The main obstacle the team faced with using the photovoltaic cells (PV cells) was the fragility of the cells and how they could be protected from mechanical damage from their surroundings. Throughout the duration of the project, numerous PV Cells were broken due to the fragility. The initial plan was to mount the PV Cells in a frame, like a picture frame, then hang them from the walls of the room. The adopted approach was to lightly tape the PV cells to a cardboard cutout using electrical tape.

Good quality sound reproduction results from good quality speakers. To achieve the best quality sound, while maintaining fiscal responsibility for the project budget, the Team purchased 3 pairs of full-range, bookshelf speakers. Each pair of speakers was rated from 15 Watts to 100 Watts output or about 50 Watts maximum per speaker. Options to rent audio speakers from the RVCC Theater Department or a local entertainment equipment business were not possible.

IX. Customer Demonstration

The first Laser-Music product demonstration was performed November1 in front of the Customer, additional RVCC Arts Professors, and a group of RVCC Music students. The Engineering Team programmed the product to the classic rock song "Black Betty". The demonstration consisted of one laser directed to each of three optical receivers. The laser was moved by the servo-motor that was driven by the programmed Raspberry Pi microcontroller.

The goal of the demonstration was to both present the progress to the Customer and to get feedback from the Customer and the Music students on how to improve the product performance. The lights of the room were turned off and the laser successfully changed direction between the optical receivers following the beat of the music and the music was projected from the speakers. The Customer and students were later encouraged to physically block the laser beam to demonstrate that blocking the beam immediately stops the sound transmission. The attendees were impressed and excited about the additional possible applications of the technology. One RVCC Dance Professor was interested about the possibility of using the technology to choreograph dance and music where the dancers would block the laser light-beams to stop the music at particularly chosen times.

X. Preparation and Final Performance

In preparation for the final “Concert” show for the product on December 7, the Customer actively collaborated in the music selection and the determination of the movements and timing of the of the laser. Engineering Team member Rodriguez, who worked most closely with the Customer for the music programming, commented that, “one of the greatest benefits of working alongside our Customer was the opportunity to see each step in the improvement of the product while delivering more details on how he wanted the final presentation to occur”.

Additionally, during this interim period, the optical receivers, amplifiers, speakers, and mirror, mechanics was improved by mounting these components to 5ft high wooden mobile mounts. This great flexibility in positioning the mirrors and speakers allowed for rapid set-up of the system and the “shaping” of the performance space to suit the audience size.

Figure 4. Preparation for the Laser-Music "Concert". Left photo showing the Customer (Strong) and Engineering Team member (Rodriguez). Right photo featuring the Laser-Music product (on table) and Engineering Team members (Rokosky, Rodriguez, and Donlan – L to R).

Over the course of the weekend prior to the "Concert", the Engineering Team spent countless hours methodically checking and testing every component, wire, and connection. The Laser Music system was tested in full multiple times. Following significant troubleshooting and debugging, the system worked flawlessly. Everything appeared in order as the day of the show approached (Figs. 4 and 5).

The night before the Laser Music product "Concert" debut, however, a laser was unexpectedly burned out, halving the anticipated two lasers and six speakers in the performance room to one laser and three speakers. Then the second laser also failed. It was already late in the evening the night before the concert and there was no product to display. There were two options at that point: postpone the showing to a later date, or draw on determination and grit and persevere to find a way to salvage the show. The latter option was chosen. Armed with a soldering iron, a multimeter, and a final remaining laser, every conceivable failure was considered throughout the night. After hours of inconclusive tests, it was found that the current to the lasers was unexpectedly high overpowering the internal laser pointer protective circuit. By 3am that night additional resistors were added to the laser circuit to reduce the current flow and resolve the overload problem.

The Laser Music "Concert" was opened to the College President, faculty, administrators, staff and Students at 12 noon the following day. Although only one laser was operational, every portion of the remaining 50% system worked perfectly and the audience was amazed by the use of laser light to transmit music and by the synchronized movement of the music to the different speakers in the room. While many professors commented and asked questions about the Laser Symphony, it was the students that asked particularly insightful questions. The enthusiasm of the Music faculty and students was particularly gratifying to the Engineering Team.

XI. Assessment and Conclusion:

This project was open-ended with no clear-cut solution, mirroring the same type of problem that professional engineers are faced with every day.

The assessment of the project success was viewed from two perspectives. The first was that the RVCC student Engineering Team delivered a fully-functioning product that met or exceeded the Customer specifications and expectations. This was a significant achievement given the challenging and open-ended problem, the Team's initial knowledge level, and the brief execution period. The second was that the responsibility of designing and delivering a real product to a real customer, and under authentic engineering conditions, was effective in accelerating student learning of important skills that are often acquired later when employed in Industry. The concepts of focusing on the Customer, doing what you say you will do, aggressive prototyping, and determination and grit, became real.

The result was a mature, cohesive, open-minded, and effective student Team that delighted their customer.

Figure 5. Preparation for the Laser-Music "Concert" continued. Left photo with Engineering Team members Rokosky and Rickman (L to R) making final product and performance-room arrangements. Right photo featuring the Laser-Music product laser and electronics (on table) and 5ft moveable wooden stands with optical detector with audio amplifier and speaker (center) and angled mirrors (left and right of center) directed at optical detectors with audio amplifier and speakers located to the left and right outside of the image.

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