Laser Etching Books in Braille for the Visually Impaired (LEBBVI)

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***Abstract* — There has always been a large gap in the accessibility of information for the visually impaired, and this paper will go through the design methodology of creating a printer for braille patterns. To bridge this gap, we used a 405 nm laser to heat up a black piece of paper to heat up a material called 'swell paper' to swell up and create a tactile pattern resembling braille. To ensure that anyone can use this device, we also have a subsystem that can translate normal text into braille. This text can be submitted via a keyboard or text file.**

I. INTRODUCTION

Access to printed materials remains a fundamental challenge for individuals with visual impairments. Although digital accessibility tools such as screen readers and refreshable Braille displays have advanced significantly, physical Braille documents continue to play an important role in education, labeling, and independent navigation. Conventional Braille embossers, however, are mechanically intricate, noisy, and costly, often limiting their accessibility in schools, libraries, and developing regions. Additionally, the raised dots produced by mechanical embossing can degrade over time through handling and environmental wear, diminishing their tactile clarity.

This project introduces a laser etching Braille printer that employs a novel indirect thermal swelling process rather than mechanical embossing or direct ablation. The system operates by directing a laser beam onto a thin sheet of black paper positioned above a substrate of swell (microcapsule) paper. The laser energy is absorbed by the black layer and converted into localized heat, which in turn activates the microcapsules in the underlying swell paper. The result is a controlled, raised Braille pattern formed through selective thermal expansion.

This indirect heating approach eliminates the debris and substrate damage associated with laser ablation while maintaining high positional accuracy and reproducibility. It also simplifies mechanical design, requiring no moving embossing pins or heavy actuation components. The prototype integrates a low-power laser diode module, precision scanning optics, and an open-source control system capable of translating standard Braille text into laser motion and intensity profiles.

The proposed technique offers several advantages: quieter operation, lower maintenance, compatibility with a variety of paper substrates, and potential for generating both Braille text and tactile graphics. Ultimately, this project aims to provide a low-cost, portable, and reliable Braille printing system that leverages optical precision and thermal transfer to expand tactile literacy and accessibility for the visually impaired community.

II. SYSTEM COMPONENTS

As previously stated, to achieve a fully functional and reliable Braille printing device, the system must integrate multiple interdependent subsystems that operate in precise coordination. Each subsystem contributes a critical role in transforming digital text into a tangible tactile output, requiring both hardware and software components to work seamlessly in tandem.

A. 2-Dimensional Gantry

At the foundation of this project is the structure in which we have created which is very similar to a 3D printer gantry but without the vertical component as that is beyond the breadth of this project. As to not reinvent the wheel, we used a tried-and-true design when building a system like this in which we have two stepper motors working in unison. The operation of the laser etching Braille printer relies heavily on precise coordination between the motion control subsystem and the laser modulation circuitry. To achieve this, a custom embedded firmware architecture was developed to handle real-time motion planning, laser triggering, and system communication.

At the core of the control system is a microcontroller, selected for its dual-core processing capability, high-frequency timers, and integrated serial communication interfaces. One core is dedicated to handling motion generation and interrupt-driven step timing, while the second core manages data parsing, user interface communication, and safety monitoring. This parallel architecture ensures that high-speed motion commands and laser pulses remain deterministic, even when background communication or file processing is occurring simultaneously.

The firmware accepts G-code–like motion commands derived from Braille text files that have been pre-processed on a host computer. Each Braille character is translated into a coordinate set representing the six-dot or eight-dot cell structure, which is then streamed to the controller in the form of discrete motion and activation commands. These commands are buffered and executed sequentially through a real-time command queue, ensuring smooth, continuous motion without pauses between cells.

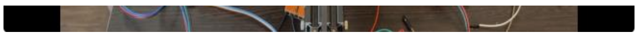

Fig. 1. Picture of the assembled gantry system

B. Motor and Laser Synchronization

The operation of the laser etching Braille printer relies heavily on precise coordination between the motion control subsystem and the laser modulation circuitry. To achieve this, a custom embedded firmware architecture was developed to handle real-time motion planning, laser triggering, and system communication.

At the core of the control system is an ESP32 microcontroller, selected for its dual-core processing capability, high-frequency timers, and integrated serial communication interfaces. One core is dedicated to handling motion generation and interrupt-driven step timing, while the second core manages data parsing, user interface communication, and safety monitoring. This parallel architecture ensures that high-speed motion commands and laser pulses remain deterministic, even when background communication or file processing is occurring simultaneously.

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C. Power Management

Reliable and stable power delivery is essential for maintaining consistent laser output, precise motion control, and overall system safety. The Power Management and Safety Subsystem is designed to regulate and distribute electrical energy across the optical, motion, and control electronics while incorporating multiple layers of protection against electrical faults, overheating, and unintended laser activation.

The system operates from a single 24V DC input, supplied either by an external power adapter or an internal regulated supply. This rail serves as the main power backbone for the stepper motor drivers and is then distributed through a series of buck converters to generate the necessary lower-voltage rails. A 5V rail powers the laser diode driver and peripheral electronics such as sensors and cooling fans, while a 3.3V rail supplies the microcontroller logic and communication interfaces. Each converter is designed with high-efficiency synchronous rectification to minimize heat generation and electromagnetic interference.

The laser diode requires precise current regulation to ensure stable optical output and prevent thermal runaway. A dedicated constant-current laser driver module receives input from the 12V rail and accepts a PWM control signal from the microcontroller for power modulation. The driver includes onboard soft-start and temperature compensation features that gradually ramp current at startup, preventing optical shock and extending diode lifetime.

The concept of the system is to take user text inputs and process it into an instruction set that is able to utilize the laser-gantry system to create raised dots on paper in the form of b[illegible]rmal use, hold sha[illegible] input is taken from a high level chip where it is parsed, translated, and sent to a low level chip that interprets the commands and maneuvers the stepper motors to progress over a grid shape where the laser will turn on or stay in sleep mode (effect[illegible] mot[illegible]ing the paper [illegible]rds ak[illegible]e laser moving from left to right similar to that of an X axis. The idea is that a user is able to type or upload text that can quickly and correctly be mapped to braille.

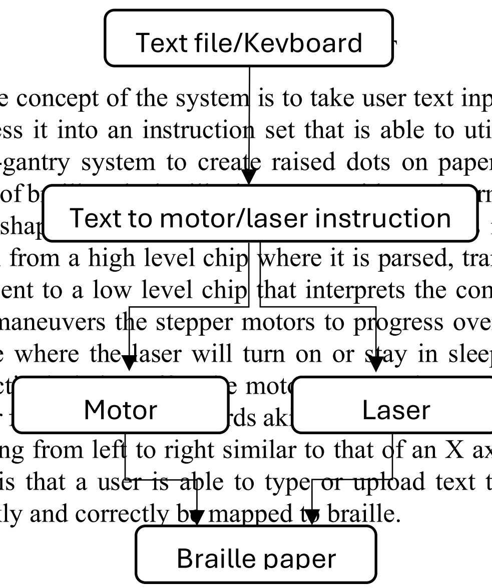

Fig. 2. System flowchart

IV. Hardware Detail

All major system components will be broken down into technical detail. This will include all ICs, MCUs, on-board regulation, laser, and peripherals. Each description will consist of a brief technical overview of each hardware component that includes how they work together, key specifications, and overall functionality of the part.

A. MSP430FR2355 – Motion and Laser Controller

The MSP430FR2355 serves as the dedicated real-time control microcontroller responsible for all motion and laser actuation tasks in the LEBBVI system. It was selected for its ultra-low-power FRAM architecture, fast interrupt response, and integrated analog peripherals, which are ideal for deterministic embedded motion control. The MSP430 interfaces directly with the DRV8825 stepper motor drivers and provides precise STEP and DIR signals for both axes of motion. Timer modules generate accurate stepping pulses and laser timing signals to ensure consistent braille dot spacing within the 2×3 grid pattern.

UART communication between the Raspberry Pi Zero and the MSP430 allows the Pi to transmit braille translation data, which the MSP parses and executes as movement and firing sequences. The microcontroller operates as a finite-state machine, advancing only when valid command packets are received and verified. Protection mechanisms include the TPS3808 supervisory circuit for undervoltage lockout, watchdog timer functionality for fault recovery, and controlled enable lines that shut down motors and the laser during abnormal operating conditions. This architecture ensures the MSP430 executes all time-critical operations reliably without interruption from high-level software tasks running elsewhere in the system.

B. Raspberry Pi Zero

The Raspberry Pi Zero was selected due to its ability to support necessary peripherals, execute high-level software functions, and communicate efficiently with the MSP430 microcontroller. During component selection, the Pi Zero was chosen over the Pi Zero 2 primarily for power, thermal, and cost considerations. The Pi Zero operates at an idle current draw of approximately 80 mA and has an active draw near 1.4 W, whereas the Pi Zero 2 draws 120–130 mA idle and peaks near 2.5 W under load. This higher current and thermal footprint would introduce unnecessary stress to the system power budget and increase heat buildup, creating potential reliability and efficiency concerns. Additionally, the Pi Zero 2 includes additional processing resources and interface ports beyond what is required for this project, making the increased cost unjustified.

In the LEBBVI system, the Raspberry Pi serves as the primary "brain," handling text input, user selection menus, file management, and braille translation logic. The Pi accepts keyboard or USB input, validates and parses user text, and converts it into contracted or uncontracted braille using internal lookup tables and error-handling routines. Once translated, braille dot data is serialized and sent to the MSP430 via UART for timing-critical motor and laser execution. Python 3 was used for software development to enable modular coding, easier debugging, and rapid iteration across the team. This architecture cleanly separates high-level processing and user interaction from real-time actuation, ensuring reliable print performance while maintaining low power consumption and system cost.

C. AC/DC Wall Adapter

The primary power source for our project is an adjustable/tunable AC/DC wall adapter power supply. This is because finding a specific voltage power supply proved to be difficult when we were looking for a specific voltage of ~16.9-17.1 volts. Therefore, an adjustable power supply was the solution. This was chosen because of our battery pack add-on which will be described below in the next major subsection. For our power supplies to work at the same time, one must be always supplying a higher voltage, so the PowerPath controller can function properly. We adjust the AC/DC to just above the maximum voltage that the battery pack can output, so the PowerPath controller will always choose wall power when plugged in.

D. Battery Pack Add-On

The battery pack accessory/add-on is for when the user wants to use the setup in an area where a wall outlet is not available; such as the middle of a classroom or larger room where outlets are not seen on the floor. We chose a 4S2P (4 series 2 parallel) battery configuration which operates at a nominal voltage of 3.6 volts and 3000mAh capacity per cell. With this configuration, we can multiply the voltage by four and the capacity by two. This means that our battery pack will typically be between 14 and 15 volts, with a maximum output of 16.8 volts. This is the primary reason why we needed an AC/DC wall adapter that has an output voltage slightly higher than 16.8 volts. The discharge cutoff voltage of 2.5 volts is also very important for our system, meaning that if the user leaves the system on for too long, we may see an overall voltage applied to the system drop to 10 volts. This is why we have added a voltage supervisory chip that can sense this and cutoff power to the load. The battery pack is also equipped with a "fireproof" and "explosionproof" bag to significantly increase the safety of the battery pack in the extreme event of a fire, explosion, etc.

E. LTC4412 PowerPath Controller

The PowerPath controller is crucial for determining what power source is supplying power to the system as the user can plug in both sources and turn both of them on at the same time. Ideally, the user chooses either the wall adapter or the battery pack, but in the case that they choose both (on accident or on purpose), the system is protected. The LTC4412 is an ideal-diode PowerPath controller which chooses the highest voltage power supply when both are on. It works perfectly in our system as one of the typical applications of the LTC4412 is that it is used for both an AC/DC wall adapter and battery source. It is both simple to implement and straight forward to use.

F. TPS3808 Supervisory Circuit

In order to protect our system from an undervoltage event, we must monitor the voltage going into the system at all times. The reason why we want to avoid a situation where we drop below our threshold voltage will be described in the voltage regulator subsection. We set our threshold voltage by using the formula found below:

$$V_{IT'} = (1 + \frac{R_1}{R_2}) \cdot 0.405 \quad (1)$$

Solving for V_IT (the threshold voltage) using 323k ohms for R1 and 10k ohms for R2, we get 13.5 volts which is 1.5 volts higher than our largest step-down regulator (12 volts). This is important and will be described in the major subsection below. Once our threshold voltage is reached, the open-drain reset will enable which controls a NPN transistor and p-channel MOSFET circuit that will switch off power between the power supply and the system at the p-channel MOSFET.

G. LM2596 Adjustable Step-Down Regulator

The regulator used to step down our power supply voltage will only require a regulator where we use different components to adjust the step-down voltage. This regulator is adjusted by feedback resistors. The efficiency of this regulator with an input voltage of 17 volts is shown below in the graph:

Fig. 3. The efficiency graph of the LM2596 regulator while ramping up the input voltage stopping at 20 volts.

Observing the graph, we can see that the LM2596 has the highest efficiency when operating with an input voltage of 17-20 volts, which is ideal as our AC/DC adapter will supply 17 volts. We also see a very slight decrease in efficiency in the range of 13.5 to 17 volts, meaning that using the battery pack will result in a hotter regulator. Alluding back to the supervisory circuit and the threshold voltage, we set it to 13.5 volts because of the 12 volt regulator. The LM2596 has a max saturation voltage of 1.5 volts, meaning that weird behavior will start to occur when the system falls below 13.5 volts. This is very important to watch out for because the 12 volts power the motors and the laser.

F. NEMA17 Stepper Motor

The NEMA17 stepper motor works with this project as it is typically paired with our motor controller (DRV8825) and mounts perfectly to our repurposed gantry system. Using a stepper motor for this project is a much smarter choice than other options as we will never have the motor spin continuously other than when we reset the position after a full line of braille has been completed. Therefore, we only need it to turn a couple of millimeters each time we want to etch a dot into the paper. Key specifications of the NEMA17 are that it has a rated current of 2A/phase, 1.8-degree step angle, and a step accuracy of +/- 5%. We will account for the rated current when designing the motor controller. We also wanted a low step angle since we only need to move a couple of millimeters between each dot, so a low step angle is ideal. It can also be reduced using modes on the motor controller. Ideally, the NEMA17 will never be using full torque as we are not spinning the rotor over a long period of time. However, a worry is the holding current it may produce when it is not rotating as the coils will stay energized to hold it in place. This will be addressed in the motor controller subsection below.

G. DRV8825 Motor Controller

The motor controller used for this project will work well with our NEMA17 motor. The MSP430FR2355 will interface the motor controller and provide the STEP and DIR pins instructions on how to move given the specific location of the dot. We can also choose from a short list of microstepping options, starting with a full step to 1/2, 1/4, up to 1/32 of a step. This is essential for tuning the motors to our liking because this will enable us to find the "sweet" spot that we need to properly space out the braille dots. The most important aspect of the motor controller is how much current it will provide to each phase of the motor, and how we control this, so we prevent overheating. Since the NEMA17 is rated for 2A/phase, we want to have the option to provide it with enough current to function, but not too close to the maximum current/phase as we want to avoid overheating issues. This is determined by the full-scale current driven by the motor which is found by determining a proper Vref and Rsense and using the formula below to calculate our IFS:

$$R_{Sense}$$

We will choose Vref by using the provided regulated 3.3 volts from the IC and feeding it through a voltage divider to calculate Vref using the simple voltage divider equation. We obtain a Vref of 1.23 volts with our resistors being R1 = 50k and R2 = 30k. Plugging this back into our IFS formula where Rsense is 0.2, we get a full-scale current of 1.23 amps, which is the maximum current driven through either of the windings; resulting in 1.23A/phase. This provides enough current to drive the motors while preventing too much current from being drawn. If we do run into overheating issues, we can simply change our R2 to a lower value.

H. Cooling System

The board will inevitably get hot with the stepper motors constantly producing holding current, as well as all other factors that increase the heat of the total board. Our primary focus on cooling will be the motor controller PCBs as the stepper motors will draw the most current out of the entire system. We have two options: on-board headers for two 5V fans where one will act as an exhaust and the other an intake, or a simple table fan. We will only use the table fan if the motor controllers are getting extremely hot because that means the motors are pulling a lot of current, and adding on-board 5V fans that consume 1W (so ~0.2 amps) will not be ideal.

I. Laser Source

The laser subsystem functions as the primary energy source responsible for localized thermal activation of the swell paper through the black intermediary layer. In this system, the selected emitter is a 405 nm gallium nitride (GaN) continuous-wave diode laser, chosen for its high optical efficiency, compact form factor, and excellent beam quality in the near-ultraviolet region. We chose a laser near the UV range because paper has a high absorption in that range.

The 405 nm wavelength lies at the boundary of the visible and near-ultraviolet spectrum, where most dark pigments—including carbon-based black paper—exhibit strong absorption. This high absorption efficiency allows for effective heating at relatively low optical power levels. The implemented GaN diode produces an optical output of approximately 500 mW under nominal operating conditions. Electrical operation of the GaN diode is governed by a low-noise constant-current driver powered from the regulated 5 V rail. The driver incorporates both TTL (digital) and analog modulation inputs, allowing the microcontroller to dynamically control laser output intensity through pulse-width modulation (PWM). The modulation bandwidth exceeds 20 kHz, ensuring precise temporal control during raster scanning operations.

A soft-start feature gradually ramps diode current during activation, preventing optical shock and extending device lifespan. The operating current is monitored through a series sense resistor, with real-time feedback digitized by the controller's ADC. This feedback enables firmware-based power stabilization, automatic calibration, and safety shutdown in the event of overcurrent or thermal fault.

V. Board Design

The overall board design consists of 10 external PCBs and a main board. We will be utilizing eight step-down regulators and two motor controllers. The board will use three 3.3V regulators, two 5V regulators, and three 12V regulators. Each 3.3V regulator will power the MSP430FR2355, act as a pull up for the DRV8825 mode selection headers, and the TPS3808. The 5V regulators will power the Raspberry Pi Zero and the LCD screen while the 12V regulators will power the laser and both motor controllers.

A focus on the design is to keep all power traces as far away as possible from the data traces. A novice way to achieve this is routing them far away from each other, so there is no noise interference. Looking at our main PCB, we have all of our power related ICs and barrel jack hookups at the top left of the board, while all the data lines are at the very bottom with the MSP430FR2355. Ideally, we would use a bunch of layers to fully isolate power traces from data traces, but that would incur higher cost and more expertise. Or we could utilize optocouplers to separate the traces. We also utilized a polygon pour on both of our layers and named it ground just as we did in Junior Design which produces low impedance return paths, improved thermal performance due to improved heat spreading, and a clean ground reference for all components which can increase signal integrity as it has a shielding effect.

Fig. 4. Assembled PCB including the motor controllers, regulators, LCD screen, various headers, and PSU inputs.

VI. Software Design

The main focus of the software design is to utilize the possible interactions between the Raspberry Pi Zero and MSP chip onboard the PCB. Using the Raspberry Pi's superior memory and high-level functionality, it serves as a "brain" for our system. Having the Raspberry Pi programmed in Python 3 enables all members of the group to have the ability to debug and tweak any uploaded code files. The ability of the chip to store vast libraries of contracted and uncontracted braille as well as the speed at which it operates, allow for the transmission of "instructions" to the MSP to allow for the control of the mechanism itself.

A. Raspberry Pi Functionality

The Raspberry Pi is the translator between the user's inputs and the commands needed to control the gantry system. The use of imported libraries in tandem with libraries created by the group help service the demands of the user and the Pi allows for us to program a large amount of error-correcting systems that allow the device to avoid any deadlock. Having the Pi control the user input portion also simplifies the code required on the MSP itself, the MSP simply sends flags via UART and the Pi returns with expected information on how to operate the gantry, move menu options forward, or restart the process. From the Pi's perspective, the code is initialized, and the program starts upon exiting sleep mode where it is immediately prepared to read user input from the on-board ports.

B. User Interface

The software operates in a steady flow; the user is prompted for an input method, grade of braille, and finally is shown a progress bar as the project is underway. As the laser moves and the process completes, the percentage bar updates, giving the user insight on the progress. The user is able to select either keyboard or USB input methods wherein the Pi will detect either a valid keyboard or USB respectively. Upon detection, if using a USB the Pi scans for correctly formatted files, in this case it will need to be a .txt. The Pi will parse the file, break the words up and determine the next steps based on contracted or uncontracted braille. Should the user select contracted, the code breaks each word up and searches the library for matches. If there are no matches, it breaks the word and determines the uncontracted equivalent. For uncontracted braille, each word is broken up into letters, and each letter assigned its correct "translation".

C. Keyboard Input

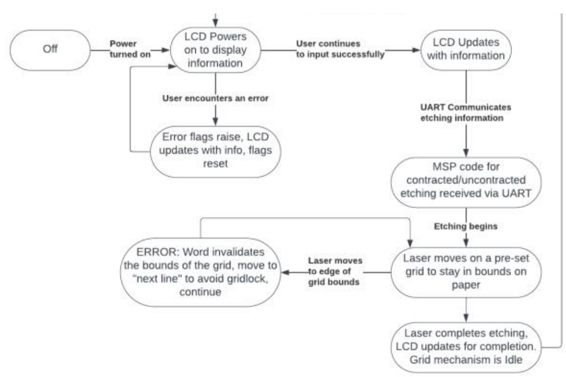

Fig. 5. MSP430FR2355 State Diagram demonstrating the operations the MSP will be performing

After the input is "translated", the translations are sent over UART to the MSP-Gantry system. This system reads, line by line, where the laser needs to turn on or remain in sleep mode. Braille is in a 2x3 grid, allowing the stepper motor to "step" over each individual grid space, the laser turning on to indent the paper at each raised spot. By the time the laser completes the final 2x3 grid, the first line of text is clearly patterned out on the paper. A grid system will keep the laser in bounds as well as preventing the stepper motor from damaging itself by attempting to move off the edge of the gantry. This grid makes it easier to operate as well, keeping the structural integrity of the braille.

The software leverages the high-level abilities of the Raspberry Pi Zero with the motor control functionality of the MSP to operate a final product to meet consumer demands.

D. Testing

To validate the MSP430FR2355 on our main PCB, we first confirmed that we could program the standalone microcontroller using the MSP-EXP430FR6989 LaunchPad as an external programmer. The SBW lines (SBWTDIO, SBWTCK, and GND) were wired from the LaunchPad to the FR2355 programming header, and Code Composer Studio (CCS) were used to verify device recognition and flash the initial test firmware. Once CCS successfully detected the FR2355 and flashed code without errors, we confirmed that the microcontroller on our board was functional and could be programmed reliably without requiring a socketed dev board.

After establishing programming capability, the next major test was UART communication from the FR2355 to the onboard LCD. A simple test program was written to transmit known strings over UART, allowing us to verify that the LCD was receiving the correct characters and displaying expected output. This confirmed that the FR2355 UART pins were mapped correctly, the level shifting on the PCB was correct, and the LCD communication path was functional. UART debugging also served as our primary method of validating system status during bring-up, ensuring the microcontroller could send feedback before final integration with the Raspberry Pi.

These tests demonstrated that the FR2355 could be flashed on our custom hardware, communicated successfully with peripheral components, and serve as the real-time controller for the system once full motor and laser firmware is finalized.

VII. CONCLUSION

The LEBBVI system demonstrates a practical, low-cost approach to producing tactile Braille using a laser-based swelling method instead of conventional embossing hardware. By combining a Raspberry Pi for high-level text processing and Braille translation with an MSP430 microcontroller for real-time motion and laser control, the device provides an accessible and affordable solution targeted toward individuals with visual impairments, caregivers, and educators. The system is designed to handle both keyboard and file-based input, perform contracted and uncontracted Braille conversion, and reliably execute dot-level actuation on a 2-D rail platform.

Compared to existing commercial Braille embossers—which are often expensive, mechanically complex, and inaccessible to most users—LEBBVI focuses on affordability, simplicity, and portability. The user interface is intentionally designed for intuitiveness, enabling a broad range of users to create tactile Braille content for education, labeling, personal reading, and everyday accessibility tasks. The dual-processor architecture distributes computational and hardware-control tasks efficiently, ensuring dependable translation accuracy and laser positioning.

This work highlights how accessible embedded design, careful power management, and modular software development can meaningfully expand access to information for the visually impaired community. Future efforts will focus on optimizing printing throughput, enhancing tactile dot consistency, refining enclosure and user interface elements, and completing full-system endurance and material-compatibility testing. Overall, the LEBBVI platform illustrates a promising direction for affordable Braille generation technology with the potential for real-world educational and accessibility impact.

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THE ENGINEERS

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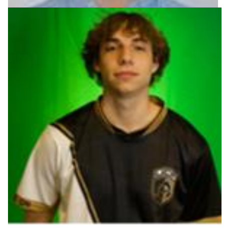
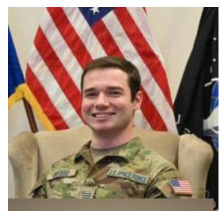
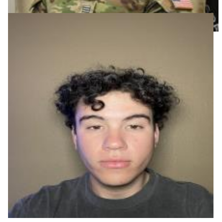


John Childs is a senior at the University of Central Florida pursuing his Bachelor of Science in Electrical Engineering. He has been a part of the College Work Experience Program (CWEP) with Lockheed Martin for a year and a half now and will begin his career with Lockheed Martin as an Early Career E.E. Circuit Designer. He plans to continue his education to pursue a Master of Science in Electrical Engineering with the University of Central Florida.



Antonio Duford is the... just adding some placeholder text here muah muah kissy kissy face ooo ahhh so many kisses hes a little military boy ooo yeah military me



Raul Perez is a senior at the University of Central Florida pursuing his Bachelor of Science in Computer Engineering (VLSI Track). He has worked with various digital and analog signal labs throughout his curriculum. He hopes to closely work with innovative artificial intelligence and digital signal processing for telecommunications companies.