Let's Have a Blast! Laser Tag

Karlie Brinthaupt, Shannon Fies,
Marco Montero, Anuj Yamdagni

Dept. of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

***Abstract* — The objective of this project is to develop a standalone, portable laser tag gaming environment to encourage people of all ages to enjoy. The end product is expected to encourage people to turn off their screens and get connected with other people (in real life) and get moving. This project was chosen by the group to foster an enjoyable design process and create a meaningful and marketable product.**

I. Introduction

Laser tag has been a popular game since its inception in the 1980s. Countless different versions have been created, each marketed with a different key feature. The basis of all versions of the game is opposing teams using toy "guns" to fire a laser beam at their opponents. The laser beam is detected by a receiving vest or hardware component and registers a certain amount of "damage" to the player that receives the hit. Each player can only fire a certain number of lasers before needing to reload their "ammunition." After registering a critical amount of "damage," a player is considered out of the game. The player still in the game after all others have reached the critical "damage" level is the winner.

This main structure of the game will remain the same. What sets this project from others like it is the portability and independence. The only pieces of equipment needed to play the game are as many "guns" as there are players, unlike most games available today that either require a separate hub or an entire devoted facility. The challenge of this product design is to determine what technologies will be functional and allow for the desired independence.

The projected is funded by the group. The budget is $200 for four (4) completed "guns."

II. Laser Tag Overivew

This section defines the hardware and software basis for laser tag in general and this project specifically.

A. Hardware description

The laser tag "guns" are typically made out of a hard plastic. Each "gun" has some sort of trigger mechanism to facilitate the creation of the laser beam. Most "guns" will have a brightly colored barrel tip to avoid confusion with a real firearm. The size of the "gun" may vary, ranging from approximately 4" (size of a small hand gun) to 22" (average size of a rifle). The final 3D model used for this project is shown below in Figure 1.

Fig. 1. 3D model of laser tag "gun" housing created in Autodesk Inventor

The 3D printed housing will hold the PCB, which includes peripheral components that enhance the game play experience. These peripherals are the OLED display that updates the user on their current game status, the LED array that indicates hit status, team identity, and battery status, the speaker that alerts a user to damage registered or a hit registered on another player using tones, and the haptic motor that provides feedback in the handle when a shot is fired or received using vibration. An additional peripheral is the accelerometer which detects the position of the "gun" and behaves accordingly ("reloading" ammunition of the "gun" is pointed down and putting the microcontroller into a sleep mode if no motion has been detected for a certain amount of time).

The laser beam transmissions sent from each "gun" typically come from an infrared diode or a laser diode. Each wireless transmission type is effective in different environments, and the intended environment is considered before choosing the transmission type.

B. Software description

The software design determines how each "gun" will react to certain circumstances and what the rules for the game play will be.

Data encoded in each wireless beam will tell the receiving "gun" which player sent the beam and how much "damage" the receiving player will register. When the trigger button is pressed, the software will send an interrupt to turn on the IR or laser diode to send a beam. When the IR or laser receiver is activated, an interrupt will be sent to register the "damage" encoded in the beam. When no interrupts are detected, the software will continuously check the status of the trigger button and receiver.

The software will also be designed to allow the users to select a game mode at the beginning of play. Game modes include "free for all," where each player is on their own, "team" mode, where players can choose or be randomly assigned to a team, each with an equal number of players, or other game modes that are variations of these two. The software adjusts how much "damage" each laser beam will do, which player is assigned to which team, which player can register "damage" to other players, and total play time for the specific game mode chosen.

C. Wireless connection

All "guns" in use in the game must be connected to a network to allow for the necessary communication for game play to begin. The game play network must know how many "guns" are in use, approximately where they are, and what their status is. The network also needs to know which player has registered too much "damage" and is considered out of the game.

D. Game play modes

To create the most entertaining user experience, there will be several game play modes available.

1. "Free for all"

The most basic game play mode for all versions of laser tag games is the "free for all." In this mode, each player plays as an individual. Every laser beam fired contains encoded information that is transmitted to an opponent's "gun" if/when the beam is received. When a beam is received by an opponent, a certain amount of "damage" is registered to that opponent. The amount of "damage" is determined by the data encoded in the beam. A critical amount of "damage" is predetermined, and when a player reaches that amount of "damage," they are out of the game. The game continues until all but one player has reached the critical "damage" level. The player that has not reached that level is considered the winner.

2. "Team"

The next game play mode is "team" mode. The underlying basis remains the same. Every beam received registers "damage" to the player that received it. However, instead of players playing individually, players are assigned to teams of equal numbers. This can be done randomly or teams can be chosen by the players. The team a player is on is indicated by the color of a specific LED on their "gun." In this game play mode, if a player on one team accidentally fires a beam at another player on their team, no "damage" is registered to their teammate. "Damage" can only be done to a player on the opposing team. The game ends when all members of one team have reached the critical "damage" level. The team with any remaining players is considered the winner.

3. Other modes

Other game play modes are being researched. The modes actually implemented for the final product depend on how much time is available before the final design review.

One additional mode is a take on the "humans vs. zombies" game available in current laser tag games. In this mode, teams are chosen randomly or by the users just as in the traditional "team" mode. One team is designated as "human" and the other as "zombie." Just as in the traditional "team" mode, a beam received by a fellow teammate will not register any "damage." The difference in this mode is that if a player from the "zombie" team registers enough "damage" on a player from the "human" team, the "human" player will actually change teams and become a "zombie." The game ends if all the "humans" have been turned into "zombies" and the "zombies" win, or a timer expires and there are still "humans" left, meaning the "human" team wins.

Another additional mode involves creating player "classes." In this mode, each player can select a "class" of player. Each class has inherent strengths and weaknesses. Two simple examples would be one class with a high rate of fire but each shot does less damage, while the opposing class would have a lower rate of power but more damage with each shot. The firing rate information would be controlled through the microprocessor while shot strength would be packaged in the laser beam transmission.

III. PROBLEM FORMULATION

The objective of this senior design project is to research and design a laser tag gaming environment that can be played essentially anywhere and requires no additional hardware.

A. Requirements of the gaming environment

Based on practical knowledge of available and necessary components, a list of the requirements has been decided on for the gaming environment.

- The dimensions of each "gun" shall not exceed 3"x8"x12"
- The cost shall not exceed $50 per "gun"
- The battery life of each "gun" shall allow more than one (1) hour of play time
- The wireless transmission range shall be greater than twenty (20) feet
- The wireless receiver accuracy shall be greater than ninety-five (95) percent.
- There shall be two (2) or more game mode selections.

IV. TEAM COLLABORATION TOOLS

For collaboration the team will need to standardize and select tools to make teamwork more efficient. When selecting possible applications, many different factors were taken into account, including support for different operating systems and mobile platforms, and presence in industry.

A. Google Drive

The sharing of files of various types is made easier by using Google Drive. This is especially important for the sharing of design documents, schematics, as well as team management documents. The team's Agile workflow schedule is also hosted on google drive, organized into a color coded spreadsheet. The online file hosting service provides a web based interface for editing documents and spreadsheets in real time, which makes the team's workflow more efficient. Google Drive also has apps for both iOS and Android, which allows teammates to work remotely.

B. Github

Although Google Drive can handle any filetype, it is more effective to use a dedicated code repository for the management of software development. Using a code repository has several benefits that make it an indispensable tool for the development of the gun's firmware. First of all, the Git protocol allows for multiple people to collaborate on the same file of code at the same time. This is done through slicing the file into its individual lines of code that are edited, thus one member can edit one section of the code without interfering with other sections of the program. The other method is through branches. Branches simply copy the state of the master branch code for further development, independent from the work of other team members. When the addition of a certain feature is complete, the branch can be merged back into the master branch. If two members edit the same section of code, a "merge conflict" occurs. Github provides an intuitive interface to resolve these merge conflicts to continue development. Another benefit of Github is its automatic versioning backup recovery options. Instead of just storing the latest copy of the source code, Github stores the changes between each commit of the source code, which means that the code can be reverted to any commit made to the repository. This is handy in the event that a bug is introduced to the repository and the code needs to be reverted to a previous version. Many bugs are expected in the codebase due to the quality of education provided by the engineering department at UCF, however the use of Github should provide an effective solution to this challenge.

C. Facebook Messenger

For general communication at all times during the day, a platform was chosen that supports instant messaging of text, memes and images. For this, Facebook messenger was chosen, for several reasons. Facebook Messenger is supported on iOS and Android, in-browser messaging, and a desktop app for Windows. This allows for the scheduling of meetings, sharing of dog pictures and general collaboration discussions. Facebook Messenger was also chosen due to its easy adoption, as all team members already had accounts and were familiar with Facebook.

V. CHOSEN TECHNOLOGIES

The group researched several available technologies for all hardware and software needs. The best technologies for size, battery life, serial communication, and network connection were chosen. Cost was considered in each selection.

A. Size requirement

The size of each "gun" is dependent on the size of the PCB and its components. A smaller PCB allows for a smaller and portable "gun." The PCB size is dependent on the component parts, therefore mounting types for hardware components were explored.

The mounting options for component parts researched are surface mounted devices (SMD) or through-hole devices. Although through-hole devices tend to be easier mount because of the attached leads, the leads make the parts larger than their SMD counterparts. There is no significant difference in cost between the two mounting types. Because of the size requirement, SMD parts were chosen.

B. Game play time requirement

Battery life and therefore game play time is dependent on the chosen battery, efficiency of the voltage regulator, and the efficiency of the microcontroller. Since the microcontroller can be put in different modes to use battery effectively, the battery selection and voltage regulator are the critical components to maximize game play time.

1. Battery selection

The group decided on using a reusable battery to increase the independence of the game play environment, since no extra batteries would be required. The reasonable available options were lithium-ion or lithium polymer.

Lithium-ion was chosen because of its high energy density, its ability to hold charge will, and its lack of susceptibility to the memory effect. The drawback to the lithium-ion battery is the need for an on-board charging monitor to prevent over-charging or over-discharging, both of which could reduce battery life or cause the battery to fail immediately. The TP4056 charging manager was chosen. This IC is able to disconnect the battery from the circuit in the case of a short and prevent over-charging from the USB. [1]

The TP4056 application circuit is shown below in Figure 2.

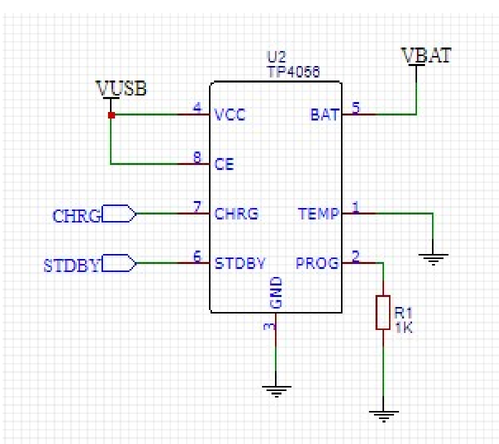

Fig. 2. Application circuit of TP4056 in final PCB design

The choices for voltage regulator technology are linear or switching. Switching regulators tend to be more efficient over all voltage ranges, but linear regulators have a lower quiescent current and dropout voltage, and are efficient in the voltage range used in the project. Linear regulators also tend to be less expensive than switching regulators. Because of the battery life requirement, a linear regulator was chosen. The final selection was the Holtek HT7333.

C. Serial communication

Serial communication is needed for transmission of data encoded in each wireless transmission between users. The options for serial communication are UART, I2C, and SPI.

Because the microcontroller supports all communication protocols, there is no cost advantage to any. I2C was chosen because it has less wires than SPI and has a high enough speed to allow efficient communication between components. The chosen encoding scheme is shown below in Figure 3. [2]

Bullet encoding Layout: 32 bits of data

| 4bits |***| 4 bits |***| 8 bits |***| 8 bits |***| 8 bits |

Prefix **team ID** **player ID** **damage value** **XOR checksum**

Fig. 3. Encoding scheme for laser beam transmissions

D. Wireless connection

A wireless network is required for the game play environment to keep all users connected as the game goes on. Options for wireless connection include WiFi and Bluetooth.

Because the microcontroller supports both communication protocols with built in modules, there is no cost advantage to either. WiFi was chosen because it is more reliable and has a wider range. The final selection was the WiFi module on-board the microcontroller.

WiFi was also chosen because of its mesh networking capabilities. The WiFi mesh allows multiple microcontrollers to send and receive simple messages without a single master connection. Each node (each "gun" acting as a node in this case) is used to transmit messages to any other node in the network. This allows the transmission of messages even between nodes that are out of range of each other by using intermediate nodes in range as hopping points. The ability of out of range nodes to communicate is crucial to this project, as the game could possibly be played over an expansive area and all nodes need to be able to communicate.

The WiFi mesh configuration also allows the network to heal itself. If a "gun" moves out of range of one "gun" and in range of another, the network will detect the movement and dynamically adjust the connections. This is done continuously and handled by the system itself. The user does not have to keep track of which nodes he/she may or may not be in range of. [3]

VI. DESIGN

All components will be housed in a 3D printed plastic "gun." To comply with political and safety constraints, the body of the "gun" will be translucent with a brightly colored top. The tip of the "gun" will be bright orange to eliminate confusion with a real firearm.

The accuracy and range components depend on the overall design. To achieve the accuracy requirement, the wireless communication receiver will be placed on the barrel of the "gun." This will allow the receiver to be in a better place to be exposed to the transmitted laser beams.

To achieve the range requirement, the wireless communication transmitter will be placed on the barrel as well, allowing the transmission to be sent without interfering with the bulk of the "gun."

Light Emitting Diodes (LEDs) will be placed on the "gun" in specific locations to enhance the game play experience. Some LEDs will remain a certain color to indicate what team a player is on. Others will flash different colors to indicate trigger status, receiver status, or battery status.

A haptic motor will be placed in the handle of the "gun" to provide feedback to the user. Vibrations of certain durations will tell the user that a shot has been fired or a hit has been received.

An accelerometer will detect the orientation of the "gun." If the "gun" is pointed down, accelerometer will detect the position and the user will not be able to fire a laser for a specified duration but will reload "ammunition" and be able to fire more lasers in the game. If the accelerometer does not detect motion for a predetermined amount of time, the microcontroller will be sent into sleep mode to preserve power.

A speaker will provide audio feedback to the user. Certain tones or short tunes will play for different actions like reloading, firing, or registering a hit.

The block diagram below in Figure 4 displays how the components will work together.

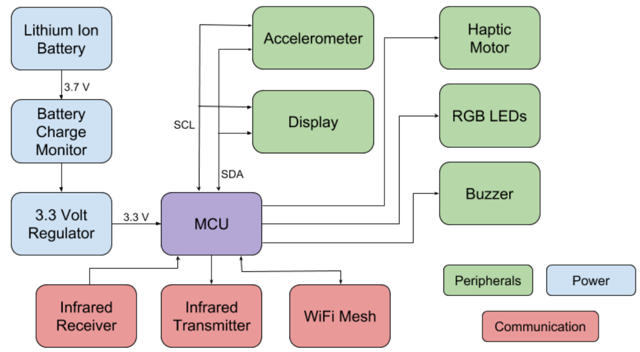

Fig. 4. Overall project block diagram

VII. MICROCONTROLLER

The group decided that the project would use a single microcontroller capable of coordinating all sensors and I/O devices. A microcontroller was chosen over an FPGA because of the greater availability of microcontrollers with different capabilities, available code libraries, and quicker code compilation and routing time

The ESP32 is one of several available microprocessors that could support this requirement, and was chosen because of the advantages it offered over other comparable microprocessors.

- High CPU speed (smooth communication between network components)
- Built-in WiFi module (simplifies project architecture)
- Compatibility with Arudino IDE (simplifies software design)
- Onboard DAC (allows audio playback on speaker)
- Internal encoder (frees up CPU for other tasks)

The ESP32 has the highest initial upfront cost, but still meets the price requirement because the built-in WiFi module saves the cost of purchasing an external WiFi module. [4]

VIII. OLED DISPLAY

The underlying goal of the project is to create a satisfying and intuitive user experience. The OLED display mentioned in Section V is a critical component to the user experience. On start-up, a splash screen image will be displayed to indicate that the display is working and the "gun" is booting up. Each component on the "gun" will be run through a test, and when each test is completed successfully, the start-up screen will be displayed. This screen gives users the opportunity to connect the "gun" and the game to the smartphone to begin connecting. From the smartphone, the game play mode can be selected.

During play, the display will show the user the time remaining in the game, the "ammunition" the player still has, the total points the player has accumulated, and the amount of "damage" the player has sustained. Pop-up notifications will be supported to alert the user to developments in the game such as registered hits, low "ammunition," player "deaths" or team victories. There will also be a small battery life indicator.

The OLED supports I2C communication, where the display is pinged at the designated address and the entire buffer of pixels is pushed to the display. With 1 bit for each pixel stored, the display is 128x64 pixels. The relatively large buffer size is still compatible with the ESP32 because of its large amount of usable DRAM. The current working OLED display is shown below in Figure 5.

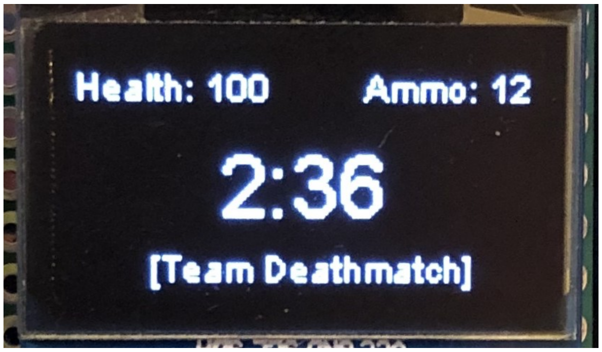

Fig. 5. Current working OLED display

IX. TESTING

At the onset of testing, each component was tested in isolation. The battery output current and voltage were tested to ensure the requirements for powering the ESP32 were met. Battery efficiency was tested by comparing output voltage to charging voltage. Charging time for the battery was also tested.

The tactile button (trigger) voltage was tested to make sure it could withstand a maximum current of 50mA. The physical trigger was also tested once 3D printed to ensure it was able to depress the tactile button correctly. The button was debounced using software to ensure a precise voltage change and by extension a better game play experience.

The LEDs were tested by making sure all of them were able to turn off and on, then tested to make sure they were receiving data correctly to display different colors. The team also made sure the LEDs were bright enough to show through the 3D printed "gun" housing. The quiescent current was measured to make sure the diodes did not drain too much current while the "gun" was turned off.

The IR LED was tested separately. The range of the IR transmitter and receiver were tested to make sure the project requirements could be met. If the desired range was not met, additional hardware (lenses, amplifiers, etc.) would be required. The encoded data was also tested to ensure that the correct information was being received with each IR transmission.

The haptic motor was tested to make sure the vibrations would not damage other components. The motor was mounted in a specific place on the PCB to ensure the vibrations could be felt throughout the entire "gun" housing while still not damaging other components. The flyback diode associated with the motor was tested to make sure it was able to buffer changes in current when the motor is turned on/off and prevent excess heat from dissipating.

The buzzer was tested to ensure game play sounds were working and could be heard in all conditions. The RAM and Flash usage for implementing sounds was tested to ensure there was enough memory in the system to contain them.

The accelerometer and display were tested together, ensuring that they were able to communicate using the I2C protocol described above. The action needed to be tested was pointing the "gun" down, having the accelerometer register the position, and transmitting that data to the display.

The microcontroller was tested to ensure that each pin was receiving the correct voltage and current required to drive the components attached to the pin. Temperature was measured to determine if any cooling systems were needed to keep the system operating safely and efficiently.

The WiFi Mesh needed to be tested to ensure that every microcontroller that could be involved in a game were able to send and receive messages. This testing included verifying mesh networking libraries, including the wrapper functions that would provide the access point to broadcast messages to the entire network.

Once all individual components were confirmed to work, they were assembled on a bread board. Testing was then done to determine if the components would work in unison when controlled by the ESP32 Development Kit. The team was able to get multiple subsystems operating on a single breadboard simultaneously. Our testing was able to incorporate the trigger button, OLED display, WS2812 LEDs and IR Receiver on the same breadboard. This proves that the components selected are a good match and that they are all compatible with each other. The operation of one will not interfere with the operation of another, and will allow for the smooth continuation of the project. The bread board set-up is shown below in Figure 6.

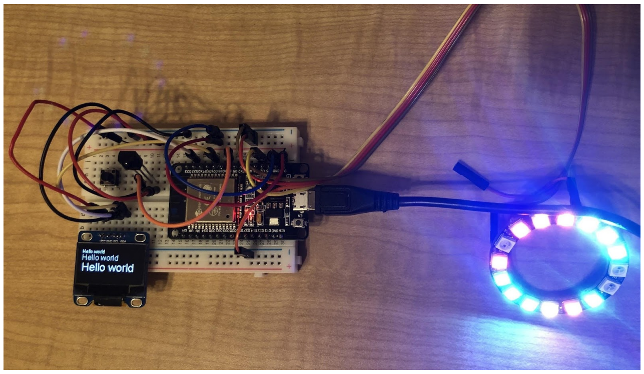

Fig. 6. Breadboard testing

Subsequent testing brought the design off the breadboard and onto a more permanent protoboard. This was the next serious step towards creating the PCB design as testing could now be done with soldered on pieces. Figure 34 below shows one of those testing protoboards with the OLED, accelerometer, IR LED and receiver, the tactile button/trigger, and underneath the ESP32, the vibration motor. Some issues were seen when pressing the button, as it would sometimes trigger the motor unintentionally, but that has been fixed with more secure coding. The OLED screen, at this juncture, can now the "Health" of the player as well as the "Ammo". Future coding and testing on the OLED has now allowed it to display more features such as the gameplay timer, health and ammo, as well as battery life. The protoboard set-up is shown below in Figure 7.

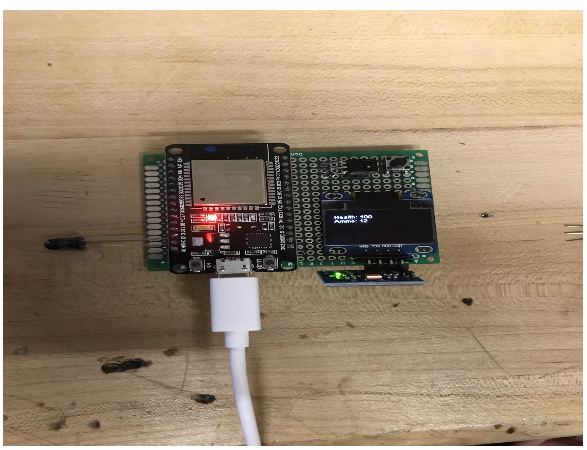

Fig. 7 Protoboard testing

X. CONCLUSION

This overall purpose of Senior Design at UCF is to teach students how to work an environment that simulates what working in industry will be like. This includes learning how to work effectively in a group, how to write a professional technical report, and how to lead meetings.

The project design gave the group an opportunity to apply the knowledge obtained from core classes to a real life, practical problem. For example, many principles taught in Electronics II at UCF came into play while selecting and mounting hardware. Electronics II emphasized learning to read data sheets which helped the group select parts based on the specs given in the data sheet, and how to use the data sheet to safely mount parts on the PCB without applying the solder for too long and burning out the part. Senior Design is one of the only academic opportunities for students to apply their knowledge and problem solving skills in this way.

The project also allowed the students an opportunity to take responsibility for a specific role while also maintaining a working understanding of things beyond their personal scope. This kind of broad grasp of the project is expected in the workplace.

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REFERENCES

[1] https://en.wikipedia.org/wiki/Lithium-ion_battery

[2] https://learn.sparkfun.com/tutorials/serial-communication?_ga=2.151809658.2127934353.1539696409-1041977720.1539696409

[3] https://computer.howstuffworks.com/wireless-network1.htm

[4] https://en.wikipedia.org/wiki/ESP32

Karlie Brinthaupt is a senior at the University of Central Florida. After graduation, she will begin her career at Harris Coporation in Palm Bay in the Signal Processing Department. She hopes to attain a Master's degree in electrical engineering with a focus on signal processing after spending a few years in industry. In her rare free time, she enjoys running, crocheting, and going to Disney.

Shannon Fies will graduate and receive her Bachelor's of Science degree in Electrical Engineering in May of 2019. She has attended the University of Central Florida for three years and plans to return to continue her education in the future. She enjoys going for hikes and kayaking and hopes to explore Florida's National Parks and Reserves prior to starting her career. She will work for Harris Corporation in Palm Bay, FL as an Electrical Engineer post-graduation.

Marco Montero, a senior student of the electrical engineering department at University of Central Florida. He is currently working in the CWEP program at Lockheed Martin Missiles and Fire Control and will begin working at Lockheed Martin Missiles and Fire Control full time this summer. He is a captain of the UCF Men's Lacrosse team and has played on the team for the past four years.

Anuj Yamdagni is a senior Computer Engineering major at the University of Central Florida. After graduation, he plans to work at a software engineering company. He enjoys petting dogs and going to the beach, and especially likes being able to do both things at the same time.