W.A.R.P – Wirelessly Accessible Record Player

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***Abstract* — The objective of this project was to create a working vinyl record player in which all manual controls of the record player can be optionally controlled remotely through a mobile application. The mobile application that accompanies the record player is also a platform with which to catalog a user's record collection, and Optical Character Recognition algorithms will be implemented in order to help the user to quickly search for records to catalog. The user can take a picture of the record label and it will be searched for automatically.**

***Index Terms* — Audio systems, bluetooth, character recognition, stepper motors, home automation.**

I. Introduction

Vinyl records, once a nearly obsolete product, have been rising in popularity. Though vinyl records and record players have many drawbacks when compared to modern digital music consumption methods, including inconvenience of use, difficulty of distribution, and increased production and manufacturing time, there are also many advantages to the record players. One major advantage of the record player is that the record player's system for generating sound is completely analog; the sound is never sampled and digitized, giving it a sound quality that is truer to the original recordings. The main goal of WARP is to remove as much of the first disadvantage – inconvenience of use – as possible in using a record player.

The main inconveniences in using a record player are tedious setup, difficulty in song selection, and the need to physically go to the record player to change songs, flip the record, lower the volume, or turn off the record player. Though the tediousness of setup are not addressed by WARP (as in, the user will still need to place the record on the platter, etc.), the difficulty in playing songs and the need to be at the record player to control it are solved with WARP.

WARP consists of two main systems: the record player and the mobile application that controls the record player. The record player maintains the ability for the user to use all manual device controls, such as moving the tonearm, and using the physical buttons on the record player. Additionally, the mobile application can be used to control the record player's power, rotation speed, and what specific song on the record is being played. Whenever a new song is selected, the record player arm will be lifted off of the record, moved to the appropriate location over the record, and then gently lowered onto the record to continue playing music. This will allow the user to have nearly full control over the record player remotely. Some new controls were also added to the record player including a 'go home' function that lifts the tonearm off of the record and moves it to the tonearm's stand and a 'anti-skip' function that lifts the tonearm and moves it over one grove to avoid skipping.

II. System Components

A. Record Player

As a record player is not being made from scratch but rather modified to meet the specifications desired in creating WARP, record player selection was an important component of designing WARP. An ideal record player would be easily modifiable (though this is a difficult specification to measure) and have a sturdy, heavy turntable. Since many modifications were to be made to the record player, the heavy turntable was key in maintaining high sound fidelity. For this project, the Stanton T.62 was chosen, as it offered great sound quality and a heavy turntable for a reasonable price.

B. Microcontroller

The microcontroller will be used to connect the record player to the user's mobile device. Commands are sent through bluetooth from the user's device to the microcontroller. The commands available are to start and stop the record player's rotation, to change the rotation speed to either 33 ⅓ RPMs or 45 RPMs, to change songs, to move the tonearm "home", or the "anti-skip" command, which lifts the arm up and lowers it back down to help avoid skipping on the record. For WARP, the Nordic NRF52832 was used.

C. Tonearm Controls

Controlling the movement of the tonearm is a key component to WARP. The two main specifications regarding the movement of the tonearm are to place the needle within 5 seconds of the designated track on the album, and to do this placement in less than 5 seconds. To meet the first specification, the accuracy of the tonearm placement must be extremely constant and accurate. More details on how these were accomplished will be discussed in Section III.

III. Hardware Design

A. Motors/Drivers

When designing WARP, one of the most important aspects is the horizontal movement of the tonearm. There were several suggested implementations for project functionality, such as using a DC motor with linear encoder or implementing a position feedback servo motor. Ultimately, a stepper motor with a planetary gearbox was chosen due to its precision and reliability. Due to the extremely small spacing between grooves on a vinyl record, a stepper motor with an extremely small step angle was needed to meet the specifications for the project. In addition to the precision requirements, the motor must also have enough torque (after step angle reduction) to move the tonearm smoothly. A standard NEMA 17 stepper motor with a planetary gearbox in addition to microstepping from a stepper motor driver reduced the step angle enough to meet the requirements.

The motor used for the vertical movement does not need to be as precise as the horizontal motor. Consistently moving from one set position to another would meet the requirements for this motor. For this, a standard NEMA 17 motor was used. The main reason for this choice was so that drivers and mounts used for the horizontal movement can be repurposed and used for the vertical movement.

The A4988 was the driver chosen for this project, primarily due to the 16th step microstepping functionality. This 16th step microstepping divides the step angle of the motor by 16, helping meet the accuracy specification of the project.. According to the A4988 datasheet, the clock period required for each step is 2 microseconds.. This corresponds to a frequency of 500KHz. However after testing, using that high of a frequency, in addition to microstepping and the gearbox, reduces the torque to an unusable level. It was decided to lower the frequency to 3KHz, which is more than sufficient to meet the required latency specification.

B. Clutch

Attaching the horizontal motor directly to the tonearm leads to several complications for the project. For example, the user will be unable to move the tonearm manually due to the holding torque of the stepper motor combined with the gearbox. This alone is a significant issue which conflicts with the specification stating that the user should be allowed to still manually operate the record player. This is not the only issue involve. While playing the record, holding the tonearm firm will cause the record to skip as well as potentially damaging the vinyl. The fix these issues, a clutch is introduced to separate the motor with the tonearm when motor control is not necessary.

Fortunately, a small electromagnetic clutch was supplied by Ogura Industrial Corporation. The clutch works by having a charging an electromagnetic coil to hold a separate disk to the inner axle of the clutch. The disk is attached to the tonearm, thus allowing separate motion from the motor when necessary.

The clutch requires a constant 12 volts in order to be engaged. When 12 volts is not supplied, the clutch is disengaged. Engaging and disengaging the clutch is controlled by connecting a GPIO pin of the MCU to the gate of a mosfet which connects the ground to the clutch. This allows for control of the clutch via the MCU.

C. Sensor

While not completely necessary for full functionality of the project, introducing a sensor helps lower the overall latency between song changes. When calibrating the tonearm back to the default location between each song change, the number of steps required is unknown. Without some way to detect that the tonearm is at the default location, the horizontal motor will keep stepping but not step past the stopper at the default location. This is the implementation used in 3D printers. This implementation is suboptimal due to the small step angle. Depending on the angle of the tonearm before movement, the motor can perform several thousand unnecessary step, potentially introducing several seconds of latency. To meet the specifications of a maximum latency of 5 seconds between song changes, this can potentially become unacceptable.

Texas Instruments' LDC0851 differential compensated and highly accurate inductive switch was chosen to detect when the tonearm reaches the default location. The LDC0851 works by giving a low voltage whenever a conductive material cover the attached inductive coils. The output of the LDC0851 will be attached to a GPIO pin and perform an interrupt on the negative edge of the sensor's output signal. The inductive coil is attached to the tonearm's resting position (which is the tonearm's "default location"). Attached to the tonearm is copper foil which reliably triggers the sensor. To ensure the the tonearm constantly stops at the same location after triggering the sensor, the horizontal motor controlling the tonearm continues to step several times.

D. Button Controls

The Stanton T.62 record player that was selected had three circuit components that needed modification – the rotation start/stop control button and the two speed control buttons. In order to allow for the microcontroller to control these circuits while leaving the actual buttons intact and functional, the record player was disassembled and inspected. After careful examination it was found that the switches worked by pulling the voltage of each of the button’s control leads from 5 V to ground. Whenever the lead is pulled low, the record player's control circuit would toggle the state of the lead that was affected.

So, in order to control each of those states with the microcontroller, a high-side switch was inserted between the record player's control circuit and ground, in parallel with the physical buttons. The high-side switch consisted of a p-channel mosfet with the source at the control circuit, gate at a mosfet lead (with the output being inverted) and the drain at ground. Whenever the microcontroller outputs at the gate pin, V_{sg} is brought above the mosfet threshold voltage, enabling the switch and pulling the control circuit lead to ground. This toggles the state of that particular control lead.

IV. Software Design

A. Mobile Application

The mobile application has been developed in the Android environment because Android requires minimal setup and uses the Java programming language. The mobile application has support for Android Marshmallow (API 23) up to Android Oreo (API 26). Android provided Android Studio IDE which contains a lot of useful tools like an emulator, a debugger, a text editor, version control, etc. that is essential for programmers.

1. Mobile Application - Calculations

The mobile application is also responsible for calculating the number of steps that the motor should move in order to choose a specific song. This calculation requires a number of factors. Because the record player rotates at either 33 ⅓ or 45 RPMs, the number of seconds of playtime per revolution can be calculated. Then, the radial distance that the stylus of the tonearm needs to be moved and the corresponding number of steps from the motor can be calculated using the law of cosines.

The formula took the following values to calculate the total number of steps: Length of the tonearm (armLength) in inches, the distance from the tonearm point of origin to the start of the vinyl record (offset) in degrees, radial angle of each step (stepAngle) in degrees, rotations per minute of the record (rpm), the calculated angle (angle), the spacing between each groove on the vinyl record (spacing) in inches, the number of steps (steps), the start time of each song relative to the beginning of the vinyl album (startTime) in seconds and place holders (x, y, and z).

$$x = (spacing * (\frac{rpm}{60}) * startTime)^{2}$$

$$y = 2 * armLength^{2}$$

$$z = \frac{x - y}{-y}$$

$$angle = cos^{-1}(z) + offset$$

$$steps = angle / stepAngle$$

2. Mobile Application - Process Flow

The figure below provides the overall process flow of the W.A.R.P. mobile application.

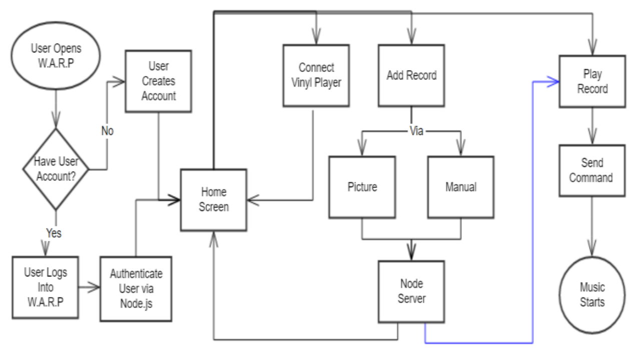

Figure 1. Mobile application process flow

3. Mobile Application - Login Screen

When opening the W.A.R.P. application, the user will be greeted with the login screen. The user will have the option to create a new account or login with an existing account. If it is a first time user, the user will begin by pressing the sign up button. The user will be brought to the signup page where the user will input their personal information and once the user's account has been successfully created, the user will be redirected to the main screen.

If the user has an account but has not logged into the mobile application, the user will be required to input their username and password and the node.js server will authenticate the user's credentials. If the user inputs valid credentials, the node.js server will send a response code of "200" to indicate success. The mobile application will save the cookie information sent by the server (session and user id) and redirect the user to the home screen of the mobile application.

If the user has an account and has already logged into the mobile application, the mobile application will automatically validate the saved cookie information and send a request to the node.js server. If the server accepts the HTTP POST request, the server will send a response code of "202" to indicate success. The mobile application will redirect the user to the home screen.

If the user receives a "404" or "500" response code, the user won't be redirected to the home screen and be required to re input their credentials.

4. Mobile Application - Sign up Screen

On the sign up screen, the user will be asked to input their name, email address, password, home address, and phone number. The mobile application will validate the email information by checking if the email contains an "@" symbol and valid domain names. The mobile application will validate the password by checking that the user input the same password twice and the password contains a capital letter, a number, and more than four characters but less than 15 characters. The user's information except the password will be stored locally on the user's device and will not be stored on the remote database.

5. Mobile Application - Home Screen

On the home screen, the user will have access to the navigation drawer or "hamburger menu" which will contain the user profile, adding bluetooth device, album search via search bar, album search via camera, adding vinyl albums manually, and logging out. The main screen will display the user's personal vinyl record collection, a floating camera button and device connection status. The camera button gives the user an additional way to add a vinyl album via camera. The device connection status describes the connectivity to W.A.R.P.. The device connection status will be labeled "Vinyl Player Not Connected" and highlighted red when it is not connected to a W.A.R.P. Otherwise, the W.A.R.P.'s connection status will be labeled "Vinyl Player Connected" and highlighted green when it is connected to a vinyl player.

6. Mobile Application - Profile Screen

The profile screen will display the user's information that was asked during the signup page. The user will have the option to update their information.

7. Mobile Application - Album Search Via Search Bar

The user will have the option to search for their vinyl record via the search bar. The user will type the name of an album and the associated artist. The mobile application will query the Discogs database for information and display the corresponding results to the user. The user will select the correct result to be added to their catalog. The user will be redirected to the music player where the user can select a song to play.

8. Mobile Application - Album Search Via Camera

The user will have the option to search for their vinyl record via the camera. The user will open up the camera and take a picture of the vinyl label. The mobile application will send the picture to a remote server that hosts the Optical Character Recognition (OCR) application. The OCR will analyze the image for the album and artist name. The OCR will send the album and artist information back to the mobile application for processing. The mobile application will use that information to query the Discogs database for results. The user will select the correct result to be added to their catalog and be redirected to the music player to begin paying a song off the album.

9. Mobile Application - Add Album Manually

Users will have the ability to manually add their vinyl album to their catalog. The user will be able to type the album name, artist name, picture associated with the album, and the number of songs on the vinyl album. The information will be saved locally on the user's phone. Reasons the user might be required to manually add their vinyl album could be due to missing or damaged labels or unable to query the Discogs database for the information.

10. Mobile Application - Logout

When the user is ready to logout, the user would press the logout button. In the background, the mobile application is going to delete the user's current session information (email, session id, user id) from a default location stored on the user's mobile phone. The mobile application will also send a HTTP POST request to the Node.js server to clear the user's session id. The user will be asked to login with username and password when revisiting the mobile application.

11. Mobile Application - Music Player

The music player will have a layout that is similar to other major music players. The music player layout will display the vinyl album cover at the top of the screen and a list of songs related to the album below the album cover. Below the list of songs, the music player will display the user's selected album and artist name on one line and the chosen song title on the next line. Following that is the media control like the play, pause, back, forward, and anti-skip buttons. The back button will make the record player play the same song from the beginning. The play button will play the selected song chosen from the song list. The pause button will stop playing music until the user intervenes and resumes playing the music. The forward button will allow the user to move to the next song in the playlist. If the user reaches the end of the song list, the record player will start at the beginning of the vinyl record and play the first song. If the user detects that the vinyl record is skipping, the user can press the anti-skip button to fix the issue.

12. Mobile Application - Bluetooth Communication

The mobile application is communicating with the embedded hardware via Bluetooth Low Energy (BT LE). The mobile application initially checks if the user's mobile device supports BT LE. If the user mobile device supports BT LE, the mobile application will check if the user has enabled BT LE. If the BT LE is enabled, the mobile device will begin to search for advertising devices with the name "W.A.R.P." If the mobile device finds W.A.R.P., the mobile device will begin to connect to the GATT Server hosted on the embedded hardware. When the mobile device has established a connection with the embedded hardware, the mobile device will begin to query the embedded hardware for a specific GATT service (transmission service) using a UUID. Once the GATT service has been found and established, the mobile application can begin transmitting data/ commands to the embedded hardware.

B. Optical Character Recognition

A picture of the record label will be processed to obtain revealing information about the record that can be used for querying the database. The image of record label will be linearly segmented to produce a series of images that solely contain the text to be processed. The segmented images are put through a convolutional recurrent neural network trained for natural image text recognition. The convolutional layers are pertinent to extract spatial features of the text image and the full-connected layers use those features to classify the text.

1.Preprocessing

From the mobile application the user will be prompted to take a picture of the record label, yet the received image will not be of the same form of the samples in the dataset used to train the model. To preserve accuracy of the model there will be a variety of preprocessing operations performed on the camera output in preparation of inputting into the network.

The most important of these preprocessing operations will be to perform linear segmentation to obtain a series of images that solely contain a line of text. The contours of the image used to perform segmentation are obtained through a combination of denoising, thresholding, dilating and eroding. Other preprocessing operations include making all images grayscale, so the number of channels is one, and resizing the image to accommodate the 128x128x1 (height x width x channels) shape of the input tensor for the network.

2. Architecture

The convolutional neural network is a form of feed-forward network that is popular due it obtaining considerably higher accuracy for image analysis tasks and will be utilized in the W.A.R.P. implementation for this reason. This network starts with two sets of convolution and max-pooling layers with the purpose of extracting features and reducing the dimensionality of the input. The convolutional layer slides 3x3 filters across the input and computes dot product between itself and the input at each position. Output from the convolution layer is known as a feature map and will maintain the height and width of the input but extend the number of channels to be the number of filters from that layer.

Max-pooling follows the convolution process and has the main purpose of reducing the dimensionality of the input while maintaining the spatial relations of the input. Keeping hold of these relations are important so the features that were extracted are not lost in size reduction. The output of each image after second max-pooling layer will be 32 x 32 x 64 and will be flattened to have the entirety of each image's values in one dimension for input into the full-connected portion of the network.

The fully-connected or dense component of the CNN will be replaced with a recurrent neural network, which has the ability to handle sequences instead of a fixed number of outputs. Each hidden layer, which there are two of, sums of the weighted inputs from the previous layer and then inputs the sum into the ReLu activation function. Bias is applied to every neuron at each hidden layer, but this will become increasingly irrelevant as the network trains more. Each output neuron will give a one-hot encoding which will be one at the index of the class that the network has predicted for each character.

Through gradient descent and backpropagation the weights of the network will be updated after each batch and once the accuracy of the network is sufficient the network weights will be saved to reinitialize the trained network at request. Testing the model is performed be simply using the weights that were saved from the training phase and running the test image through the network after preprocessing.

2.Dataset

Due to the specific nature of analyzing text from a record label, the network was originally going to be trained using a self made dataset. Each sample in the record label dataset consisted of the raw image and a text file, that contained the pixel positions of text in the image and the corresponding label for each of the pixel positions. The accuracy of the network after being trained using this dataset was not up to the requirements of the project, making need for a dataset that could properly train the network.

The self made record dataset was replaced by the MJSynth Dataset, utilized by Max Jaderberg in his study of automatic text detection in the natural world. Consists of 9 million images of natural text words and training, tuning & testing splits predefined, the MJSynth was a prime candidate for training the network for performing optical character recognition on lines of text in images. The change from inputting the raw image, as it was with the original dataset, and inputting images that only contained text was the reason why the linear segmentation of the image is necessary.

C. Embedded Programming

On startup, the microcontroller is programmed to initialize all bluetooth low energy protocols, begin advertising to nearby devices, and to initialize all used pins to either an input or output. Once the microcontroller has connected to a device, it awaits an event from the connected device. The commands that are sent from the user's device are comprised of up to 5 bytes. The byte sent represents the command type and the rest of the bytes are optional details that may be used by that command type. Below is an outline of the workings of each event type.

1. Start/Stop

If the first byte of the command sent is a 0, this corresponds to the start/stop command type. No other details are needed to execute this command, so all other data sent, if any, is ignored. This command causes the pin that controls the state of the turntable rotation to be brought high for 200 millisecond.

2. Speed Select Commands

The speed control command type corresponds to a 1 in the first byte of the command that was sent from the user's device. The following byte corresponds to the speed that the user selected – a 0 for 33 ⅓ RPMs and a 1 for 45 RPMs. Similar to the start/stop control, the corresponding pin is brought high for 200 milliseconds to toggle the record player's speed.

3. Song Select Command

If the first byte of the command sent is a 2, the song select command type was sent. The following 4 bytes sent from the user represents the number of steps that the tonearm should move in order to select the correct song. This value is calculated by the mobile application based off of the song time chosen by the user. When this command is sent, the following sequence of events occurs:

The record player is stopped, and the clutch is engaged to allow for control of the motor responsible for horizontal movement of the tonearm. Then, the motor that controls the vertical movement of the tonearm is moved 200 steps clockwise in order to lift the arm. Each step on a motor is caused by outputting to the corresponding pin, delaying, stopping the output to the pin, and repeating this for the desired number of steps.

After the tonearm is lifted, it is moved to the outside edge of the record player in order to recognize an "initial position". This is a calibration step used to increase the accuracy of the song selection. At the "home" position of the record player arm (the stand that the arm can rest on), there is a sensor that outputs to the microcontroller whenever the tonearm touches it. This causes an interrupt in the microcontroller. The horizontal motor is then moved in the opposite direction for whatever number of steps was sent by the microcontroller, and lowered back onto the record player. At this point, the clutch is disengaged to allow free movement of the tonearm, and the record player is started again.

4. Go Home Command

The go home command type corresponds to a 3 in the first byte of the command sent. This command causes the tonearm to be lifted and returned to the "home" position, which is found using the sensor.

5. Anti-skip Command

The anti-skip command type causes the tonearm to be lifted and lowered back down at the same location and is invoked by sending a 4 by the user's device.

D. Remote Server

The remote server has three main purposes: user authentication, creating an easy to query endpoint for Discog's API, and to run the OCR algorithm. The server is programmed in JavaScript using the Node.js framework. It uses the express node module, which is a library to quickly implement a server. The server makes available certain routes, and whenever a user makes an HTTP POST request to the routes, the server processes the response accordingly.

Authentication occurs whenever the route "login" receives a request containing an email and password. The password hashing algorithm implemented uses 20,000 iterations of the password-based key derivation function. The password and a 180 byte salt are passed into this function to create the user's password hash. From there, the user is given a session that is stored in the cookies of the logged in device in order to allow for regular use of the server.

There are other routes that were created to intermediate queries to discogs. The server has an access token that allows it to query the Discogs API. So, whenever the application user searches for a record, the search parameters are sent to this server, which in turn forwards the request to Discogs. The response is processed to allow for easier use and returned to the client. If the user chooses to catalog the record, it is stored on the server’s database for quick access.

In order to reduce the load of intensive OCR algorithms on the user’s device, all OCR is performed on this server as well. The client-side application will make a POST request to the “searchImage” route, sending along the data of the picture taken. The raw image sent from the client is segmented and run through the OCRNet as described in the "*Optical Character Recognition" section.* The result from the model is used to query Discogs to find the corresponding record.

V. RECORD PLAYER MODIFICATIONS

A. *Tonearm Controls*

Vertical movement of the tonearm presented a challenging problem to overcome. The main difficulty was finding a solution to allow the tone arm to be gently placed on the record without pushing on it, potentially damaging both the needle and the record. To solve this, an arm was created to rest on top of the arm to stop it from falling down. This arm is then raised to gently place the needle onto the surface of the record. Note, the tonearm is not physically attached to this holding bar, but rather it is placed on top of it. Using several other pieces and joints, the rotational movement of the stepper motor was converted to a vertical movement of the holding bar. The figure below displays a 3D model of the vertical movement design. Ultimately the individual pieces were simplistic enough that laser cutting the pieces were sufficient.

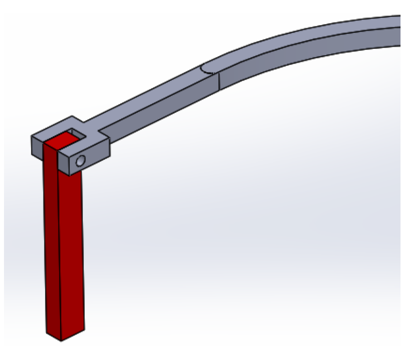

Figure 2. Vertical Movement Design 3D Model

To control the horizontal movement of the tonearm, the tonearm must be connected in some way to the horizontal motor. However, direct connection between the arm and the motor leads to complications. This is the reason a clutch is used.

The horizontal motor is secured in place on top of the metal bottom of the record player. Secured onto the shaft of the horizontal motor is the main portion of the clutch. The disk that is magnetized to the end of the clutch when engaged rests on the clutch. The disk is secured to a wood piece via screws. A nylon standoff is screwed into this wooden piece which is then attached to the bottom of the tonearm. This allows for independent movement when the clutch is not engaged and for controlled movement when the clutch is engaged.

B. *Other Modifications*

In order to make space for components underneath the turntable, the metal bottom of the record player is spaced by multiple standoffs. The Stanton record player modified for WARP had thick plastic standoffs in order to create space of the multiple PCBs originally used in the record player. To extend the base even further, holes were drilled into these rubber standoffs and 3" nylon standoffs were screwed into the holes.

With the standoffs in place, a large gap between the bottom and top of the record player was created, revealing the inner electronics. For aesthetics and to protect the internal components, a duck canvas cover was draped over the sides of the record player. This covering is secured in place by cut velcro strips. Velcro strips are used to allow easy access to the WARP signal PCBs for demonstration purposes.

BIOGRAPHY

Martin Do

Martin Do is attending the University of Central Florida and working towards his Bachelor’s degree in Computer Engineering. He plans to enroll into graduate school to earn his Master’s degree in Computer Engineering. His contribution to the W.A.R.P. project was the design and development of the android mobile application. He also worked on integrating and establishing communication with the embedded hardware and server application.

Jose Medina

Jose Medina is a computer engineering student with an interest in artificial intelligence applications, particularly in the machine learning area. For W.A.R.P he was in charge of the computer vision and 3D modeling tasks. He also took on a secondary role for development on the server and mobile application

Micaiah Reid

Micaiah Reid is an electrical engineering student focused on controls and embedded systems. For WARP, he was in charge of PCB design, embedded software implementation, circuit prototype design and testing, and remote server implementation.

Daniel Weinberg

Daniel Weinberg is currently a senior at the University of Central Florida. He plans to graduate with his Bachelor's in Electrical Engineering in 2018. Daniel hopes to pursue a career in FPGA and digital hardware design after graduation.

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