PIXEL High Level Design
Precise Image eXtraction and Enhancement Lab

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1 Introduction

Digital cameras have shown a resurgence in popularity in recent years, capturing the interest of photographers and hobbyists alike. Smartphones have mostly replaced consumer cameras in today's market due to their convenience. However, smartphone cameras are often missing features found in standalone digital cameras. Furthermore, even current digital cameras face limitations in usability and image management. Team PIXEL is addressing these challenges with an innovative digital camera design. Our project focuses on optimizing the functionality, efficiency, and user experience of a digital camera, leveraging modern technologies to deliver smarter image capturing and sharing capabilities.

Our solution is a digital camera powered by an ESP32 camera module, capable of automatically uploading captured images to a shared album over WiFi. By integrating AI-based facial recognition, the system ensures that only relevant photos are shared with individuals present in the pictures, saving users the hassle of sorting through large, generic albums. With an onboard microSD card for local storage and a color OLED display for real-time previews, our camera offers an all-in-one solution for modern photography enthusiasts. This project not only simplifies the photo-sharing process but also enhances the quality and creativity of digital camera photography.

2 Problem Statement and Proposed Solution

Digital cameras are making a comeback, valued for their image quality and nostalgic charm, but they still face significant limitations that hinder their usability in today's fast-paced, interconnected world. One of the main challenges is the lack of accessibility of the images once they are captured. Unlike modern smartphones, which seamlessly integrate with cloud services for instant photo backup and sharing, digital cameras often require manual intervention to transfer images. It can be a burden to upload all of your photos after an event or trip and add them to a massive shared album, individually inviting each person you have taken a picture of. Additionally, the reliance on proprietary or outdated connectors and cables adds to the inconvenience of downloading and sharing images from a digital camera. Many users lose the original cords needed to connect their cameras to laptops or find that these cords are incompatible with newer devices. This forces users to either buy new accessories or rely on external card readers, which adds cost and complexity. For casual users, this technical barrier can lead to frustration, while for professionals, it can slow down workflows and delay the delivery of images to clients. Similarly, digital cameras often have a very limited memory, so only a fixed number of images can be stored on the device. This limitation means that to take new pictures, old ones must be deleted, or pictures must be downloaded off the device and stored on external memory every time it is used. These difficulties of uploading and saving images create a significant usability gap that limits the potential of digital cameras in a world in which immediate, cloud-based solutions exist.

It is also difficult to set up a self-timer photo with just a digital camera and also know that everyone is in frame, especially given that no one is actually holding the camera. When you set up a camera on a bookshelf or ledge so that everyone can be in the photo, you often have to go through several iterations of starting the timer, getting into position, waiting, and then checking to see if the photo turned out well. The taker of the photo also has to rush to push down the timer button and then get into frame, which can be chaotic, resulting in a lower quality photo. Even if the correct framing is obtained, the images are often still low quality because of too bright or dull lighting.

To address the limitations of traditional digital cameras, we propose developing a smart, WiFi-enabled digital camera that not only takes high-quality images but also integrates seamlessly with cloud services and provides enhanced usability features. Our solution is designed to eliminate the need for extensive manual intervention in photo transfers, simplify group photography, and solve lighting challenges.

Instant Image Upload and Sharing - This solution employs the ESP32 camera module and WiFi to take images and automatically upload them to a cloud integration platform, such as Google Drive or a custom website. As part of this uploading process, an AI facial recognition algorithm developed using OpenCV will be used to recognize who is in each picture and create individual pages of the website or albums for each person. Then, everyone will not have to sort through all the pictures in the entire collection and can easily find the ones relevant to their use. In the event that the camera is not connected to WiFi, there will also be a microSD card onto which the images can be saved so that the internal ESP32 memory is not instantly filled and the images are not lost forever if a connection is not available. This solution eliminates the need for individually downloading and sharing each image, external cords or accessories, and the limited memories of current digital cameras.

Self-Timer and Framing - The proposed solution for the difficulties of taking a self-timer photo and correctly framing the group in a shot will be addressed with a separate button clicker and laser levels. A small, handheld, wireless device that is separate from the camera will have a button that is connected to the camera ESP32 over bluetooth that someone can click and the photo will be taken. They will be able to be in the camera shot without having to directly press the button on the camera and then run to be in the picture. Additionally, four laser line levels will be used to project a rectangular outline from the camera. This box will represent the frame that is actually being captured by the camera. This way, even though there is not someone holding the camera and looking through the viewfinder, the group can ensure that they are properly positioned in the shot.

Adjustable Flash Brightness - To address the fact that many digital camera images are overexposed due to the flash being too bright or too dark due to the lack of a flash, an adjustable flash system is proposed. A potentiometer will be used to adjust the brightness for a camera flash LED driver. The user can turn the dial on the potentiometer based on if they want the full flash brightness, no flash, or variable levels in between. This solution will allow bright images or objects to not become washed out and dark images and spaces to clearly, effectively be photographed.

3 System Requirements

Camera and Imaging Requirements

1. The camera must be able to take a picture when a certain button on the camera is pressed.
2. The camera must be able to take a picture when the button on a remote control is pressed.
3. The remote control must be able to send a signal over Bluetooth in real-time when its button is pressed.
4. The pictures taken on the camera must be an accurate representation of the field of view and color that the user sees through the viewfinder.
5. An OLED screen should preview the image before it is taken.
6. The camera must be able to correctly outline the field of view of the camera with lasers for remote image taking.
7. The user must be able to press a button to enable the laser frame.
8. The camera must be able to display the correct image after capture on an OLED screen.
9. The camera must be able to take a picture with reasonable clarity (5 MP, 2560 x 1920 pixels) while still being within the processing capabilities of an ESP32 [1].

Connectivity and Data Management

10. The camera must be able to connect to WiFi.
11. The camera must be able to connect to Bluetooth when a user presses a button to search for Bluetooth devices.
12. The camera must be able to send a captured image over WiFi to a cloud-based platform (website or app).
13. The pictures must accurately be received over the WiFi (correct color, field of view, image type).
14. A GPS device must be able to record the location when an image is taken.
15. The location, time, and date of each image must be able to be sent over WiFi and received by the client website.
16. The GPS, time, and date information must correspond to the correct image.
17. Users must be able to access the website or app.
18. The website must be able to use an AI facial recognition algorithm to group together images of the same person.
19. The website must display separate albums for the people who appear in multiple photos.
20. The AI facial recognition algorithm must be adequately trained so that it avoids as much bias in identification as possible.
21. The website should also have an option that allows the specified users to view all of the images shared with them, even if they are not in that exact photo or the photo is not of people.

22. If a website is used, it should be easily accessible. If an app is used, the user should be able to download it to their own personal device, such as an iPhone. Either interface should be user friendly.

Power and Indicator Requirements

23. A battery should be able to power the microcontroller, lasers, LEDs, and flash. 3.7 volt lithium ion batteries in series should be utilized.
24. The camera battery must be able to be safely recharged.
25. There must be an LED to indicate when the camera battery is low.
26. There must be an LED to indicate when the camera is fully charged.
27. The charging LED should turn off when the device is removed from the charger.
28. The camera electronics must not overheat or discharge too much heat that it is uncomfortable to the user.
29. The battery life of the camera must be on par with other cameras, lasting at least 3 hours.

Safety and Accessibility

30. The camera must be able to correctly outline the field of view of the camera with lasers.
31. The laser outline must be visible to the people in the self-taken image.
32. The lasers must be Class IIIA (between 1 mw and 5 mw) for eye safety [2].
33. Lithium ion batteries should be used for charging and user safety.
34. The buttons on the camera should be labeled so that the user knows which one corresponds to which functionality.

Practicality of Device

35. The camera should be the same or smaller in size and weight than typical digital cameras (height - 2.4 inches, width - 4.16 inches, depth - 1.6 inches, weight - 2 lbs) [3] [4].
36. The camera should be comfortable to hold and use. The buttons must be in convenient locations so the user can press them while also looking at the screen or viewfinder.
37. The buttons must be easily pressed by the user.
38. The remote control must be able to interface with the camera from up to 25 feet away [7].
39. The camera and cloud client communications must not interfere with other WiFi transmissions.
40. The camera must be able to stand up on its own so that the user can walk away and take the image with the remote control.
41. The batteries can be recharged with a pre-existing charging cord or device that most people already own.

Additional Camera Features

42. The camera must have an adjustable flash that can be controlled with a potentiometer by the user.
43. The flash must go off right after the user presses the button to take the image.
44. The flash must be able to be turned completely off.
45. The flash brightness must correctly correspond to the dial turn on the potentiometer.
46. There must be an LED that indicates when an image is taken.
47. The camera must be able to save captured images to an SD card if the user chooses to do so.
48. The camera must be able to take images and save them to an SD card even when it is not connected to WiFi.
49. The user must be able to press buttons to decide to upload an image to the website or to delete it, and the camera should either begin sending the image data or delete the image.
50. The camera must be durable enough to withstand small water droplets and be placed in a bag.

4 System Block Diagrams

4.1 Overall System

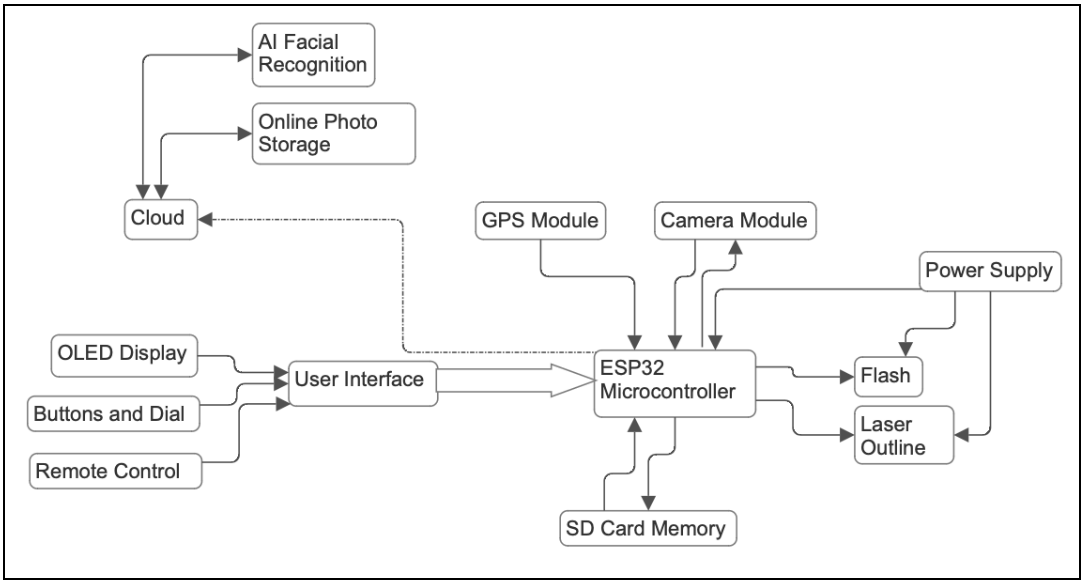

Figure 1. Overall system block diagram for image capture and storage.

The interface requirements for the system fall under the subsystems of the design.

4.2 Subsystem 1: Camera Control Module and Interface

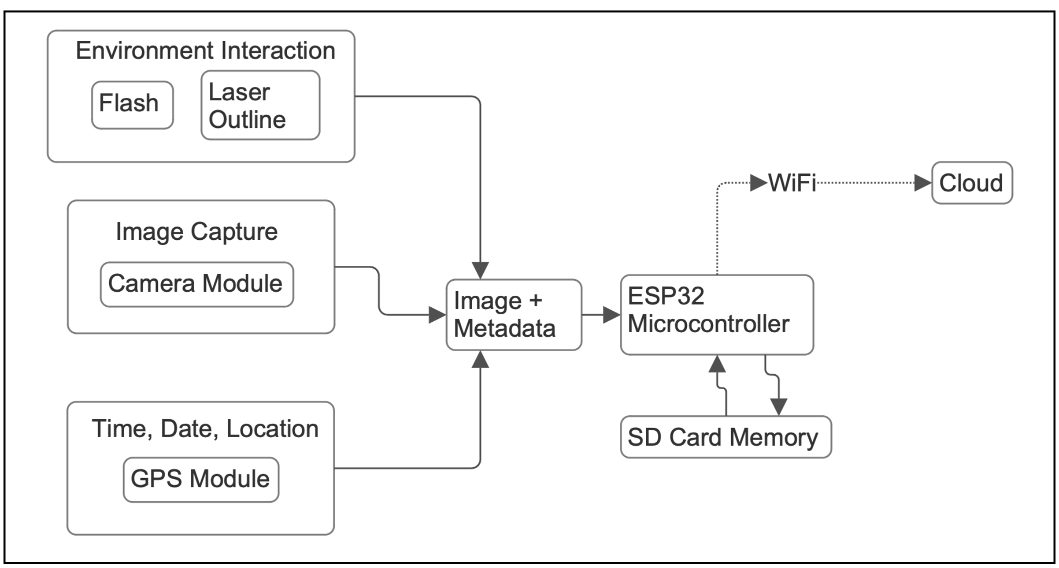

Figure 2. Subsystem that shows how components interact with the environment of the image to be taken, how the image and its meta data are combined and then sent to the microcontroller, and how the microcontroller either stores the image in on-board memory or online via WiFi.

Interface requirements for this subsystem:

- Camera flash is adjustable via user interface
- Laser outline is set to bounds of image to be taken and must be powered appropriately
- Camera module takes the photo and sends it to the microcontroller via board wiring
- GPS module gets metadata via satellite and sends it with the corresponding image; if no satellite data is available, time and location will have to be gathered using WiFi
- Image and metadata is sent to the microcontroller which uploads it to the cloud via WiFi; information is stored in SD card memory if internet connection is not available

4.3 Subsystem 2: Power

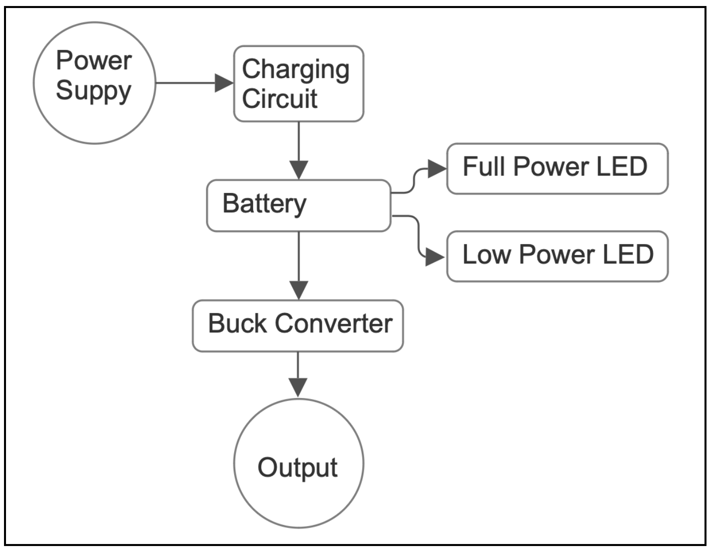

Figure 3. Subsystem that shows how the battery is charged via charging circuit, how the battery voltage is stepped down via buck converter, and how the battery charging level is indicated via LEDs.

Interface requirements for this subsystem:

- Battery is charged via charging circuit, which accounts for overcharge protection, voltage regulation, over discharge protection, overcurrent protection
- Charging circuit must provide same or greater voltage than what is needed for the battery
- Battery voltage is stepped down to desired output voltage
- If battery is low, red LED turns on; if battery is charging and is full, green LED turns on; LED turns off if charger is unplugged

4.4 Subsystem 3: User Interface Description

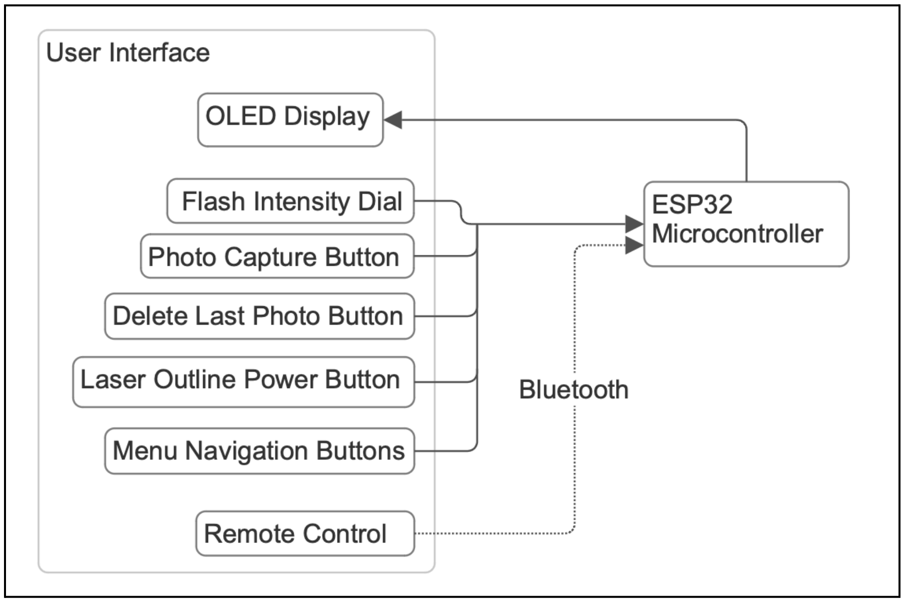

Figure 4. Subsystem that shows the user interface and how relevant data is sent to the OLED display, how a dial controls the flash brightness, how buttons control various photo capture and storage options, and how a remote control takes a photo via bluetooth connection.

Interface requirements for this subsystem:

- OLED display is wired to the microcontroller
- Flash intensity dial is connected to ESP32 analog input pin
- Buttons are connected to microcontroller
- Remote control interfaces with microcontroller via bluetooth

4.5 Subsystem 4: Cloud/Post Processing

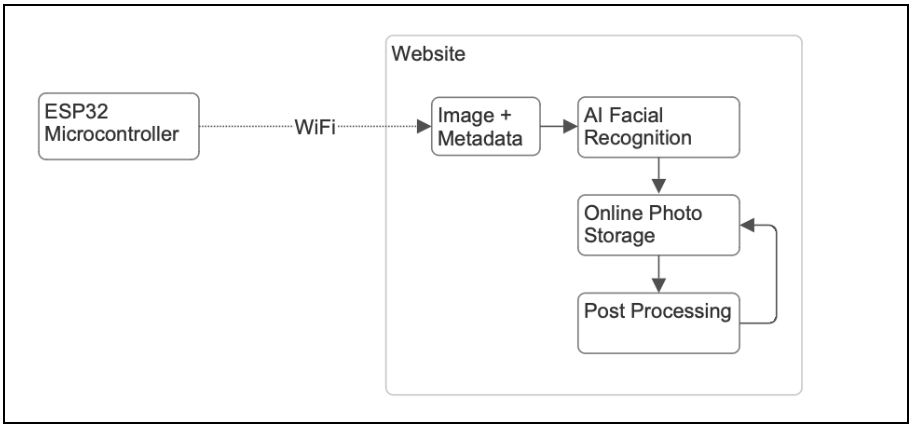

Figure 5. Subsystem that shows how an image along with its metadata is uploaded from the microcontroller to the cloud via WiFi connection, how that image is sorted according to facial recognition, and how any post processing is done on images in storage.

Interface requirements for this subsystem:

- Microcontroller sends images and metadata to the website via WiFi connection
- Website must recognize that a given image and its metadata are connected and save that information accordingly
- AI facial recognition checks incoming images against its database of registered faces and organizes the image accordingly
- Images receive post processing if user decides so on the website

4.6 Future Enhancement Requirements

The requirements and subsystems described above apply to the initial release of our product. For future iterations, there are additional, more advanced features that we would like to include.

1. **Zoom**: A future version of the camera would have a zoom dial to adjust the field of view. The laser outline would then need to update accordingly to match the new image bounds.
2. **Auto flash brightness**: Instead of the user adjusting the flash brightness with a knob, the flash intensity would adjust automatically depending on the lighting of the environment.
3. **Wireless charging**: Rather than having to plug in the batteries or camera to recharge, a future version could include a wireless charging dock for the device.
4. **Smartphone connectivity**: In addition to an app or website, there could be a feature that allows for images to be uploaded directly to a user's camera roll. This would be similar to Apple's AirDrop.

5 High Level Design Decisions

Camera Control Module
Function: The camera module control subsystem handles capturing images, associating metadata, and transferring the data to the ESP32 microcontroller. The subsystem also manages adjustable flash, laser outline framing, and storing images either in onboard memory (SD card) or uploading them to the cloud via WiFi.
Camera Module: We chose the Mega 5MP SPI Camera Module with Autofocus Lens to capture high-resolution (5MP) images. This module integrates easily with the ESP32 via an SPI or I2C interface and provides clear, detailed images for various lighting and focus conditions. Its documentation and support simplify integration and development.
GPS Module: We chose the NEO-6M GPS Receiver Module to capture real-time location and timestamp metadata. It communicates with the ESP32 via a UART interface. If GPS data is unavailable, the ESP32 gathers time and location information through WiFi-based services. This ensures accurate metadata for every image captured.
Laser Frame: We chose a low-power laser module (Class 2 or Class 3R) to project an outline representing the camera's field of view. The laser module provides an adjustable beam focus and ensures users can accurately frame shots when using remote capture functionality.
SD Card Memory: We chose a microSD card to provide local storage for images and metadata when WiFi connectivity is unavailable. This ensures that no data is lost and images can be uploaded to the cloud once a connection is restored.
ESP32 Microcontroller: We chose the ESP32-S3-WROOM-1-N16R8 as the central controller to manage image capture, metadata integration, and data transmission. It interfaces with the camera module, GPS, flash, and laser modules and supports WiFi for cloud uploads and Bluetooth for remote control functionality.

Power
Function: The power subsystem is responsible for providing a stable and portable power source for the entire device. It includes a charging circuit to recharge the battery safely and LEDs to indicate battery status. The design focuses on ensuring reliable power delivery, protecting against overcharge/discharge, and giving users clear feedback on battery status.
Power Supply: We have chosen to use two lithium-ion batteries in series, which typically provide a combined voltage of 7.4V. This configuration offers greater capacity and runtime for powering the ESP32, camera module, and other peripherals. To achieve the required operating voltage of 5V, we will use a buck converter chip to step down the voltage efficiently. This setup ensures reliable power delivery in a variety of environments and use cases.
Charging Circuit: We chose to implement a Li-Ion battery charger and protection module for charging the battery via a USB port. This module will provide effective charging and include essential protections such as overcharge protection, overcurrent protection, and short-circuit protection. To achieve the required operating voltage of 7.4V, we will use a boost converter to step up the 5V USB input to 7.4V for charging two lithium-ion batteries in series. This setup

offers a straightforward, cost-effective solution that can be easily recreated with readily available components.
Full Power LED: We chose a green LED to indicate when the battery is fully charged. This LED turns on when the charging circuit detects that the battery has reached its maximum charge capacity. It provides clear visual feedback that the device is ready for use.
Low Power LED: We chose a red LED to indicate a low battery level. This LED turns on when the battery voltage drops below a safe threshold, prompting the user to recharge the device. This helps prevent unexpected power loss during operation.

User Interface on Device
Function: The user interface provides controls and real-time feedback for capturing an image and showing device status.
Display: We chose a color OLED display which will display the most recent image taken as well as other information. We chose this device because it is SPI-based and can be easily integrated with our microcontroller. It also fulfills our requirement of offering real-time image preview and status feedback, making the camera more user-friendly.
Flash Brightness Control: We chose to integrate a potentiometer into our system design to allow for user-adjustable LED flash brightness to achieve precise lighting in different conditions. A potentiometer, as opposed to push buttons or other controls, offers a more smooth way to control brightness.
Basic User Controls: We have chosen to include push buttons for the basic functionality of the camera: capturing an image, uploading to cloud, deleting an image, enabling the laser outline. We wanted our camera to have a wide range of enhancements and features but not be overly complicated for the user. For our bluetooth remote control, we chose a shutter remote, which enables hands-free capture with simple ESP32 integration.

Cloud/Post Processing
Function: The cloud/post-processing subsystem handles the transmission of images and associated metadata from the ESP32 microcontroller to a cloud-based storage platform. The system sorts and organizes images using AI-based facial recognition and offers post-processing options to enhance the user experience and improve image quality.
Image and Metadata: We will utilize the ESP32-S3-WROOM-1-N16R8 microcontroller to integrate image capture and metadata (timestamp and GPS location) before transmitting the data via WiFi. The NEO-6M GPS module provides accurate location and time information, ensuring each image is contextually enriched when uploaded to the cloud.
AI Facial Recognition: We chose OpenCV for AI-based facial recognition to analyze incoming images and automatically detect and classify faces. This allows images to be organized into individual albums, making it easier for users to find relevant photos.

Online Photo Storage: We chose a cloud platform, such as a custom app or a custom website, to store images along with their metadata. This ensures images and metadata remain connected, accessible, and organized for seamless retrieval and sharing.
Post Processing: We chose to implement OpenCV on the cloud platform to provide optional post-processing features such as filtering and cropping. This allows users to enhance image quality after upload through a simple web interface.

6 Known Unknowns

While we have an end product in mind and a good understanding of the necessary subsystems, there are some aspects of our project that we are still unsure how to implement. The following list briefly discusses these known unknowns:

1. **Camera module selection**: Through our research, we've seen example parts with prices that vary based on the quality, so we need to decide how much funding we're willing to allocate. We will likely want to purchase some inexpensive parts for testing purposes but then choose a higher-quality model for our final design.
2. **Laser feature**: The goals of the lasers are to project an outline of the camera's field of view so that users can easily tell what is in the picture, especially when using the remote control to take the photo. Our idea is similar to that of a laser level: four laser lines on the front of the camera that form a box. We will need to figure out how to correctly position and power the lasers and make sure the frame matches the field of view. There are also some concerns about how effective this feature will be. It should theoretically work well when the image background is something simple like a wall, but we're not sure if it will be useful when the background is busier or has more depth.
3. **Bluetooth remote connection**: In order to incorporate the remote control device, the microcontroller will need to establish a bluetooth connection with it. We envision this process to be similar to how you press a button on a bluetooth speaker to have it search for available connections. The camera will need to have a way for the user to turn bluetooth mode on to allow for the connection to be made. We also need to consider whether the connection will be dropped after a certain period of inactivity.
4. **Charging specifics**: As the power subsystem describes, we have decided on the type of battery we want to use (a 3.7V rechargeable lithium ion battery). However, we have not yet come up with a specific charging circuit. We also need to decide how we want the user to charge the batteries. The batteries could be built into the case and require the user to plug in the entire device to charge, or the batteries could be removable and allow the user to have multiple sets of batteries and never have to plug in the device itself.
5. **Online sharing medium**: We know that we want to use a cloud-based platform to upload our images to, but we are still deciding between a website or an app. With a website, we would need to acquire a domain or use a website builder (e.g., Wix, Google Sites). An app could be more accessible since most users likely want the images on their phones, but we would need to do more research into what developing an app would entail. We also need to consider any associated development costs like domain registration and app store listing fees. With either option, the platform must be user-friendly, easy to access, and support our AI facial recognition feature. Another key consideration is whether the platform should be public or private. A private platform would likely be more difficult to implement but could make more sense if users have concerns with the privacy of their images.

6. **Temperature regulation**: As the subsystem diagrams illustrate, this device will have numerous components in a small enclosed space. One of our concerns is the camera overheating, especially with parts like the LEDs, lasers, and battery. We likely will need to include heat sinks on our board and may have to consider a more active cooling strategy, such as incorporating a fan. The casing will also need to have ventilation to allow for proper airflow and heat dissipation.

7 Major Component Costs

For **wireless communication**, we have determined that the technology of the ESP32-S3-WROOM-1-N16R8 microcontroller is best suited for our needs. It has built-in WiFi and Bluetooth capabilities. It eliminates the need for additional wireless modules, reducing costs and simplifying the design. It can handle data transmission and control operations efficiently, has 16MB of flash memory, and costs around **$10**.

For **image capture**, we are planning on utilizing the Mega 5MP SPI Camera Module with Autofocus Lens [5] , which has easy integration with the ESP32 via an I2C or SPI interface. It offers high image resolution (5 MP) and is also well-documented on their website for more straightforward integration. It costs around **$35**.

For our **user interface**, we will include a color OLED display [6] which has SPI-based communication and allows for real-time feedback and mode indication. Users will be able to preview their photos and monitor device status easily. It will cost around **$20**.

For our **power supply**, we plan on using two 3.7V Lithium-ion batteries with a charging circuit for a portable, rechargeable power source. This reliable battery source will ensure uninterrupted operation in a variety of environments. We estimate the cost for two to be around **$20**.

We will also include push buttons for **user input** (taking photos and selecting options), LEDs for **mode indication**, and a potentiometer or dial to **control the brightness of the flash**. These parts are in lab stock and widely available.

For the actual **camera flash**, we plan on using a Dual LED Flash Driver with Boost Converter [7] which provides high-intensity light for low-light conditions. It will cost around **$5-$10**.

For the **enclosure for the camera**, to ensure its protection, we will custom 3D print a case in the EIH. It will provide a durable, lightweight housing for components. This will most likely be free from the EIH with the curriculum code.

We will need to implement **cloud integration**, which we are thinking about doing through Google Drive or a custom website to support image upload and remote post-processing. It will be free to develop.

For the **image post-processing**, we will use OpenCV [8], an open-source computer vision library, which provides advanced image processing functions, including filtering, enhancing, and object detection. It is free and highly adaptable for use with ESP32 or external platforms for local or cloud-based processing.

For the **built-in GPS,** the system will utilize a GPS receiver module, specifically the NEO-6M [9], which is suitable for capturing data in real time. The GPS module will communicate with the ESP32 over a UART serial interface. The ESP32 will parse the GPS data strings to extract the required location and time information. The cost will be around **$30**.

The **circuit board** itself will be a custom PCB and integrate the microcontroller, peripheral connections, etc. and will cost around **$50**.

For our **laser outline framing feature**, we will implement a low-power laser module [10] (either class 2 or class 3R laser module) with adjustable beam focus, with GPIO control for turning on and off. It can be integrated with the ESP32 for timed operation and user control and will be eye-safe under normal use conditions. The cost is projected to be around **$10**.

For the **remote control button** to take a picture from far away, we plan on using a prebuilt bluetooth key fob button [11] to communicate over bluetooth with the ESP32. We will pair the bluetooth key fob with the ESP32 using its Bluetooth low energy capabilities, program the ESP32 to listen for and interpret the key fob's button-press signal and then once received, trigger the ESP32 to activate the camera module to capture an image. These buttons are widely available online. The CamKix camera shutter remote control with bluetooth wireless technology is one such button. This will cost around **$10**.

Assuming no additional unforeseen expenses, we project the overall cost to be around **$210 total** for this project.

8 Conclusions

Our project seeks to modernize and enhance the functionality of digital cameras by addressing common limitations such as inconvenient image sharing, limited memory, and poor lighting conditions. By leveraging the ESP32 microcontroller and integrating AI facial recognition, real-time WiFi photo uploads, and intuitive user controls, our design offers a seamless photography experience. Features like a laser outline for framing, remote-controlled photography, and an adjustable flash brightness provide innovative solutions that simplify and elevate the user experience.

This smart camera design is important because it bridges the gap between the nostalgic appeal of digital cameras and the convenience of modern, interconnected devices. By automating tedious tasks such as photo uploads and organization, and by providing tools for improving the user experience, our camera not only enhances usability but also empowers users to capture and share memories effortlessly. With its innovative features, robust engineering design, and focus on solving real-world problems, this project demonstrates the potential to make a meaningful impact in the field of photography and personal technology.

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