Animal Aware - Smart Trail Camera

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

Bobby Calhoun, Tate Forcella, Rio Laney, Alyson Williams

MENTOR: Dr. David Coe

CPE 495: COMPUTER ENGINEERING DESIGN I
CPE 488: CYBERSECURITY ENGINEERING CAPSTONE I

ELECTRICAL AND COMPUTER ENGINEERING
UNIVERSITY OF ALABAMA IN HUNTSVILLE

emails: jtf0016@uah.edu
bc0043@uah.edu
rl0059@uah.edu
aaw0020@uah.edu

Smart Monitoring and Detection

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- Common users of Trail Cams are: Campers, Wildlife Monitors, Hunters, Park Rangers
- The Smart Trail Camera (STC) provides benefits to monitoring, protection, and analysis
- Employs new novel techniques for high classification accuracy and response time
- Utilizes inexpensive technologies lowering cost
- Allows for more personalized use of trail camera software

Smart Trail Camera: Animal Image Classification

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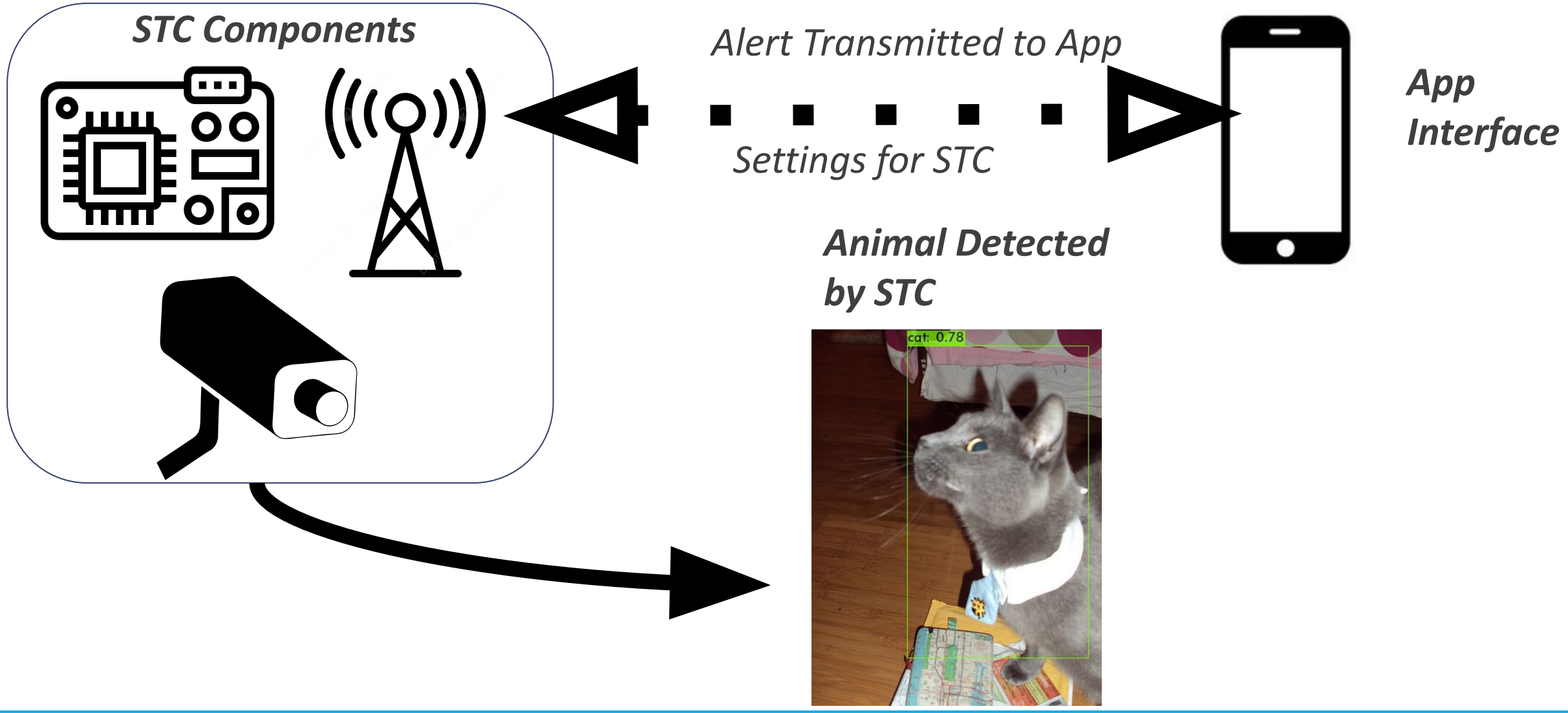

Marketing Requirements

Marketing Requirements	
M1	Identification of a variety of common animals (Where users can select phone notifications according to detected animal.)
M2	App customization that supports at least four smart trail cameras that can generate alerts simultaneously
M3	Tamper-proof app interface
M4	Motion activated so that the cameras can maintain a good battery life.
M5	Works even without direct network access
M6	Supports multiple connections from cameras with the app.
M7	Alert source must be viewable in the application

Engineering Requirements

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Engineering Requirements	
ER1	Animal classification with 50% accuracy against separate specifically chosen testing data.
ER2	Animal classification in wild with 25% accuracy in environments with proper setup, and lighting.
ER3	Secure and encrypted multi-camera connection and configuration within app interface.
ER4	30 Day battery life under average daily load (4% active SoC computation in a day).
ER5	Activation of SoC within 0.8 seconds of Motion Detection.
ER6	Connectivity with up to a 25-meter (~90 feet) range.
ER7	Simultaneous multi-camera connections without data loss.
ER8	Real-time alerts to the Android device indicating the node information within 6 seconds.

Survey: Market & Competition

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Three key aspects the STC aims to achieve is: performance, price, and functionality.

WiseEye MiniCam [https://wiseeyetech.com/product/wiseeye-mini-cam/]

- Automatic Species Recognition
- 32GB SD Card for Storage
- Long Range Cellular Antenna
- 65 ft. IR Flash
- $199.99 / $139.99(on-sale)

Analysis - Very Expensive, Unnecessary Features add to cost

Tactacam REVEAL Pro 3.0 [https://www.amazon.com/TACTACAM-Cellular-Required-RV-TC-XPRO3-Surveillance/dp/B0D7HZKFCQ]

- 4K UHD Photo
- LTE Cellular Network
- $154.99

Analysis - Very Expensive, No Image Classification, Requires Mobile Cell Carrier

Survey: Existing Projects

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- WiseEye [1], a trail camera company, was looking to develop a user-customizable open source platform that would allow more flexible camera traps for wildlife researchers.
- A user named Trail Camera Training [2] was developing an animal detection system using trail cameras.
- A study [3] by the Department of Forest Resources Management in Canada looked at object detection in camera trap object identification. Can you put authors &/or paper title
- A study titled "Innovations in Camera Trapping Technology and Approaches: The Integration of Citizen Science and Artificial Intelligence" [4] looked into the integration of artificial intelligence into trail cameras to create neural networks to identify different animal species.

1. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0169758
2. https://universe.roboflow.com/trail-camera-training/trailcam-detection
3. https://www.sciencedirect.com/science/article/pii/S2351989422001068
4. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7023201/

Survey: Existing Patents and Projects

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- There was a paper in 2017 where the authors were looking for a way to automate the processing the large amount of data the “camera traps” produced. They aimed to create a neural network were their experimental results produced 96.6% and real world results of 90.4%. Animal Recognition [1]
- Patent: #9,626,580 [2] Defining region for motion detection
- Patent: US11537891B2 [3] Intelligent recognition and alert methods and systems

1. https://ieeexplore.ieee.org/abstract/document/8259762
2. https://patents.justia.com/patent/9626580
3. https://patents.google.com/patent/US11537891B2/

Possible Approaches

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1. Perform inference on edge device, then send results mothernode which is used for interop to phone.
2. Gather video/images from edge device and stream to mothernode to perform compute.
3. Gather video from edge device and send to mothernode for interop to phone to perform compute.

Favorable - Perform inference on edge device, then send results mothernode which is used for interop to phone.

Possible Approaches (AI/ML)

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- Pugh Chart over where to perform model inference/analysis.
  - Favorable is Inference on Mothernode

		Inference on Edge Node	Inference on Mothernode	Inference on Phone
Cost	**3**	0	-1	+1
Reliability	**4**	0	+1	0
Experience	**2**	+1	+1	-1
Easy to build/develop	**1**	-1	+1	0
Score		1	4	1

Possible Approaches (Network Connectivity)

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- Pugh Chart over what form the network connectivity should take.
  - Favorable is Radio

		Radio	LoRa	ZigBee
Cost	**4**	0	+1	-1
Reliability	**3**	+1	0	0
Distance	**3**	+1	+1	0
Bandwidth	**6**	+1	-1	0
Score		12	1	4

Risk Analysis

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- Project components and associated risks:

Component	Potential Risks
Camera module	poor image/video quality, power drain, lens malfunction
LED	burning out, harder to make covert
Mobile application	application bugs or crashes, security vulnerabilities, compatibility issues
Motion Sensor	false positives, false negatives, failure to detect motion, environmental impact

Risk Analysis

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- Project components and associated risks:

Component	Potential Risks
Android Phone	incompatibility with application, battery drain
Microcontroller	firmware bugs, overheating, limited processing power
Network Connectivity	loss of signal, security breaches, high cost
Artificial Intelligence	false positives/false negatives, accuracy, dataset poisoning

Project Summary

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- Targeted Impact:
  - Aims to provide the market with new and innovative animal aware smart trail camera
  - Implementation of novel AI classification techniques on low compute edge devices
  - Reduction in price due to low compute environment

- Significance:
  - Automating Animal Identification
  - Customizable Alerts
  - Real-time Access

- Degree of innovation:
  - AI/Machine Learning integration
  - Expansion on existing trail cameras in terms of price and function
  - Multi-use functionality, including hunting, wildlife conservation and research, and property security.

Functional Decomposition:

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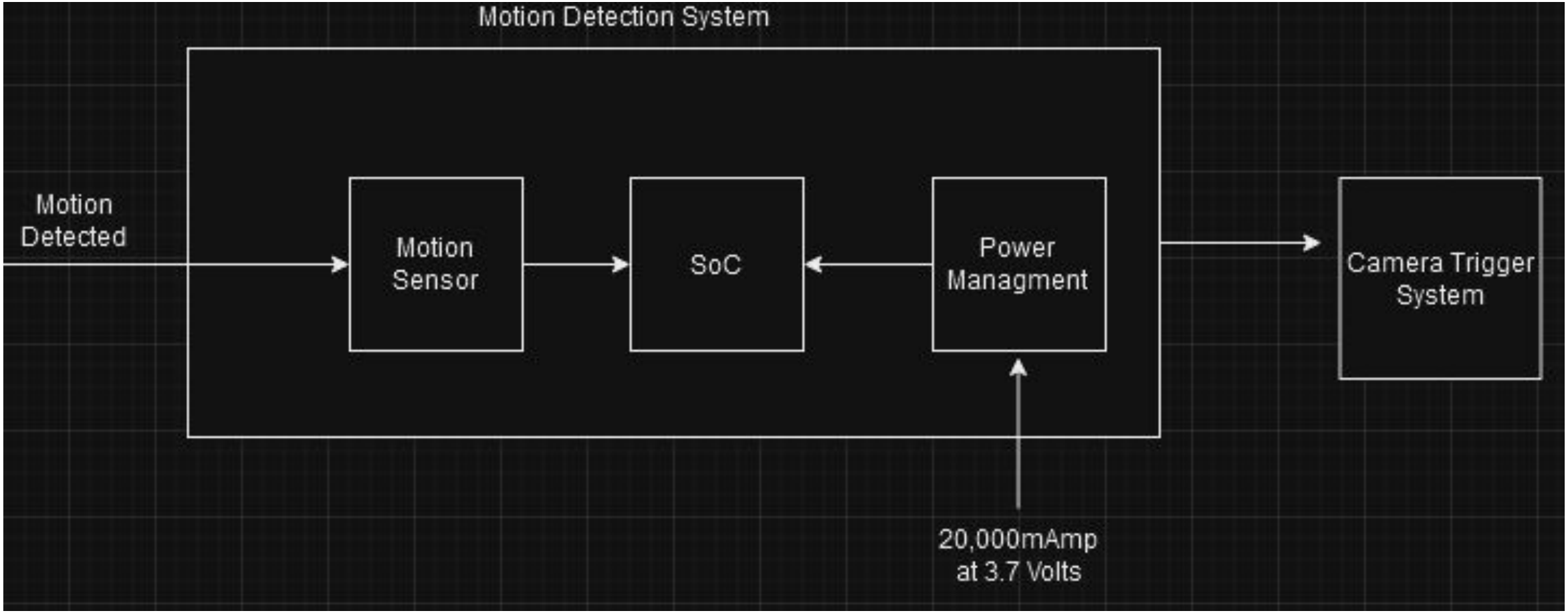
Module	Motion Detector
Inputs	Sensor detects motion inside the environment
Outputs	Signal interrupts SoC waking camera from sleep Trigger camera to start recording
Functionality	Detect motion to activate the camera for capturing images or video.

Functional Decomposition



Functional Decomposition:

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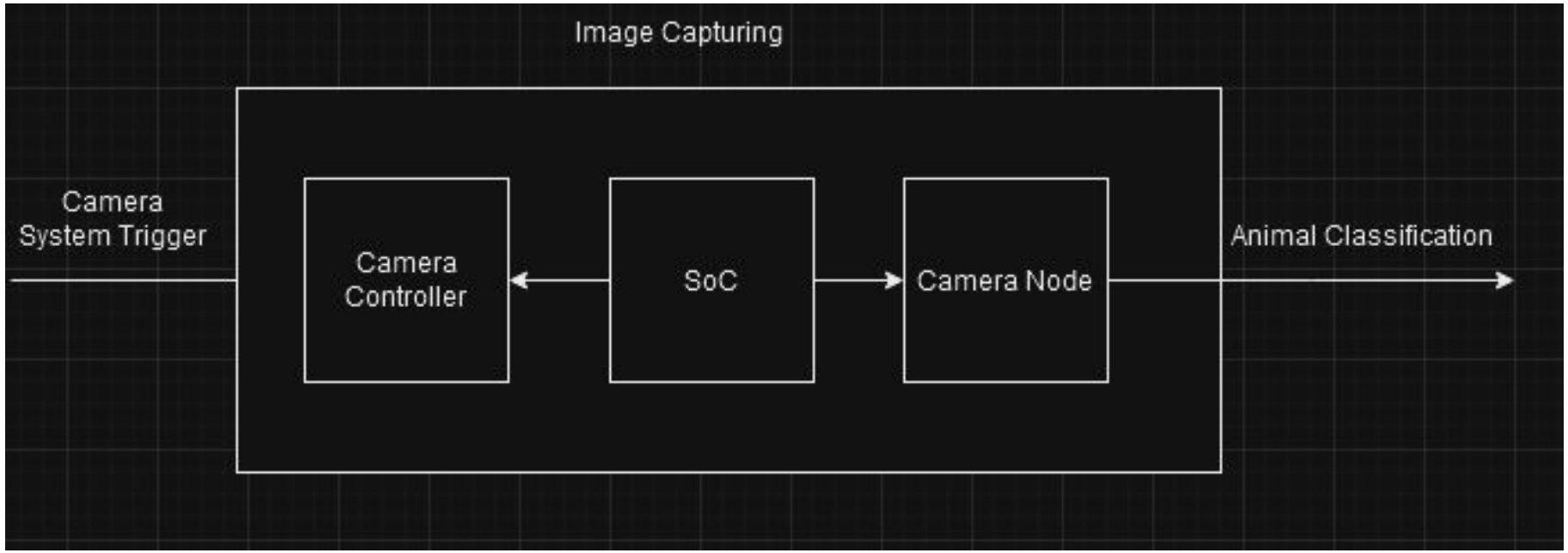
Module	Image/Video Capture Device
Inputs	Trigger SoC to initiate recording
Outputs	Unprocessed image or video data
Functionality	Capture images or video upon motion detection

Functional Decomposition:



Function Decomposition

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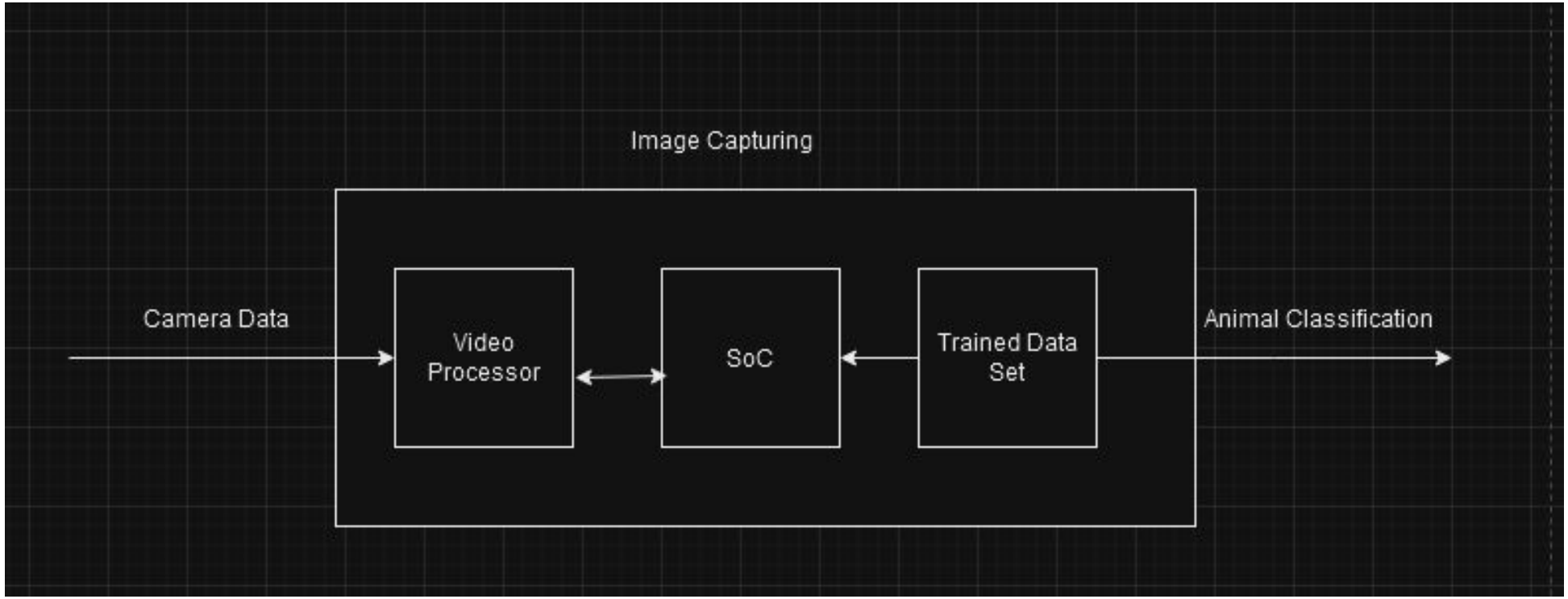
Module	Image Classifier
Inputs	Raw image or video data from the camera sensor.
Outputs	Bounding box confidence score for each assessed classification. (i.e. <Bird, 90%>)
Functionality	Capture images or video upon motion detection

Functional Decomposition:



Functional Decomposition:

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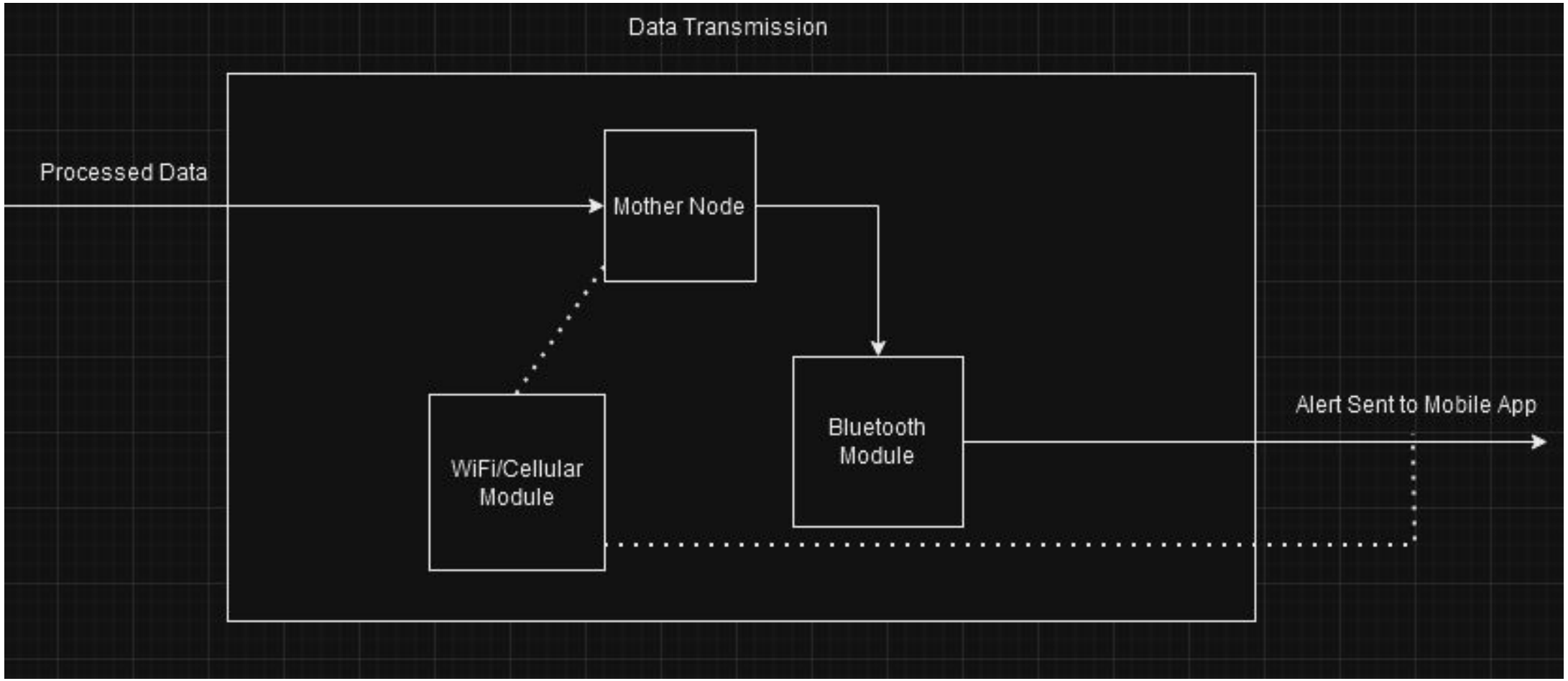
Module	Mothernode - Data Transmission and Communication
Inputs	Radio Transmission of classification results and captured data from the camera.
Outputs	Alerts and data sent to the mobile app.
Functionality	Transmit alerts, video, and classification results to the mobile app via Bluetooth or WiFi Radio.

Functional Decomposition:



Functional Decomposition:

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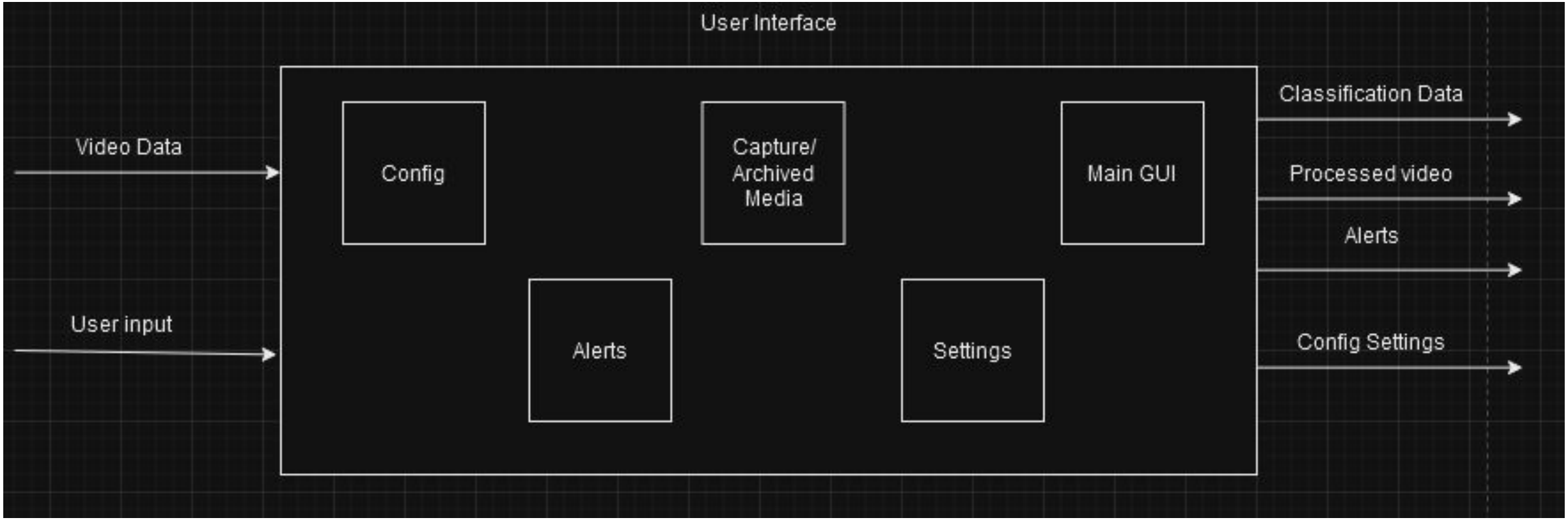
Module	User Interface
Inputs	Network - Data transmitted from the camera (via Bluetooth or WiFi). GUI - User configuration and camera settings.
Outputs	Display captured data, classification results, and alerts. Confirmation of updated configuration settings from received node to the camera.
Functionality	Allow users to configure camera settings, view alerts, and review captured data.

Functional Decomposition:



Functional Decomposition:

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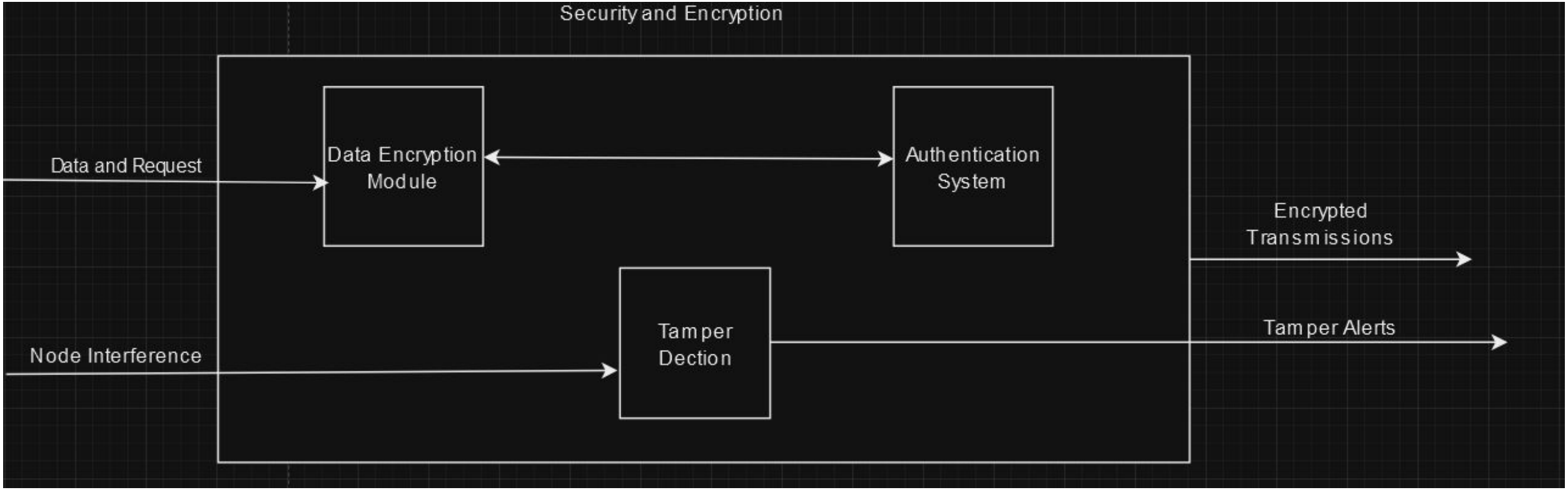
Module	Security and Data Encryption
Inputs	Video Data User Request
Outputs	Encrypted data transmissions to the mobile app. Tamper alerts if unauthorized access is detected.
Functionality	Ensure secure communication between the camera and the mobile app to prevent unauthorized access

Functional Decomposition:



Functional Decomposition:

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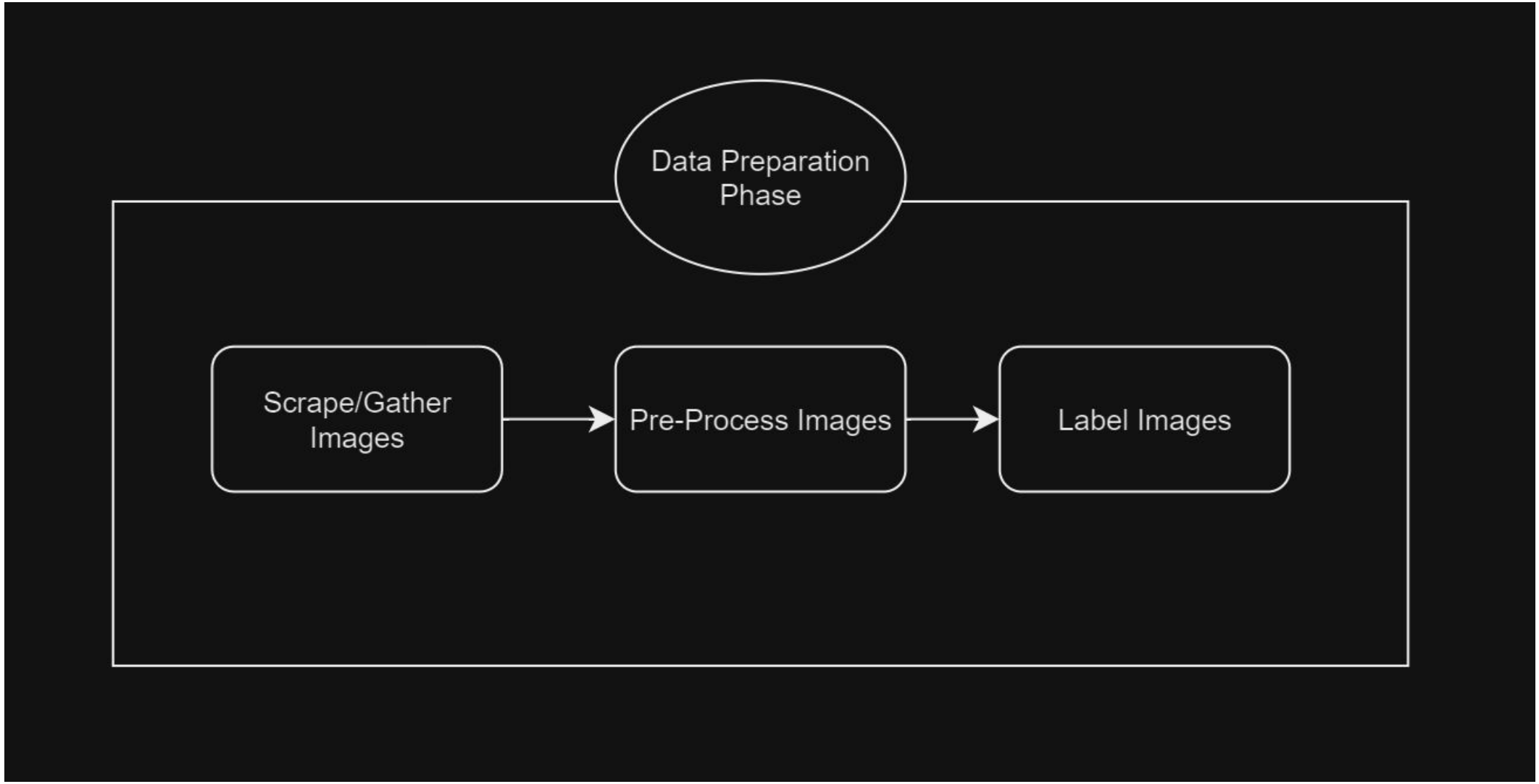
Module	Data Preparation
Inputs	Video or Images
Outputs	Labeled and Preprocessed Images to fit into Database
Functionality	Prepares Images for utilization in database/model training

Functional Decomposition:



Functional Decomposition:

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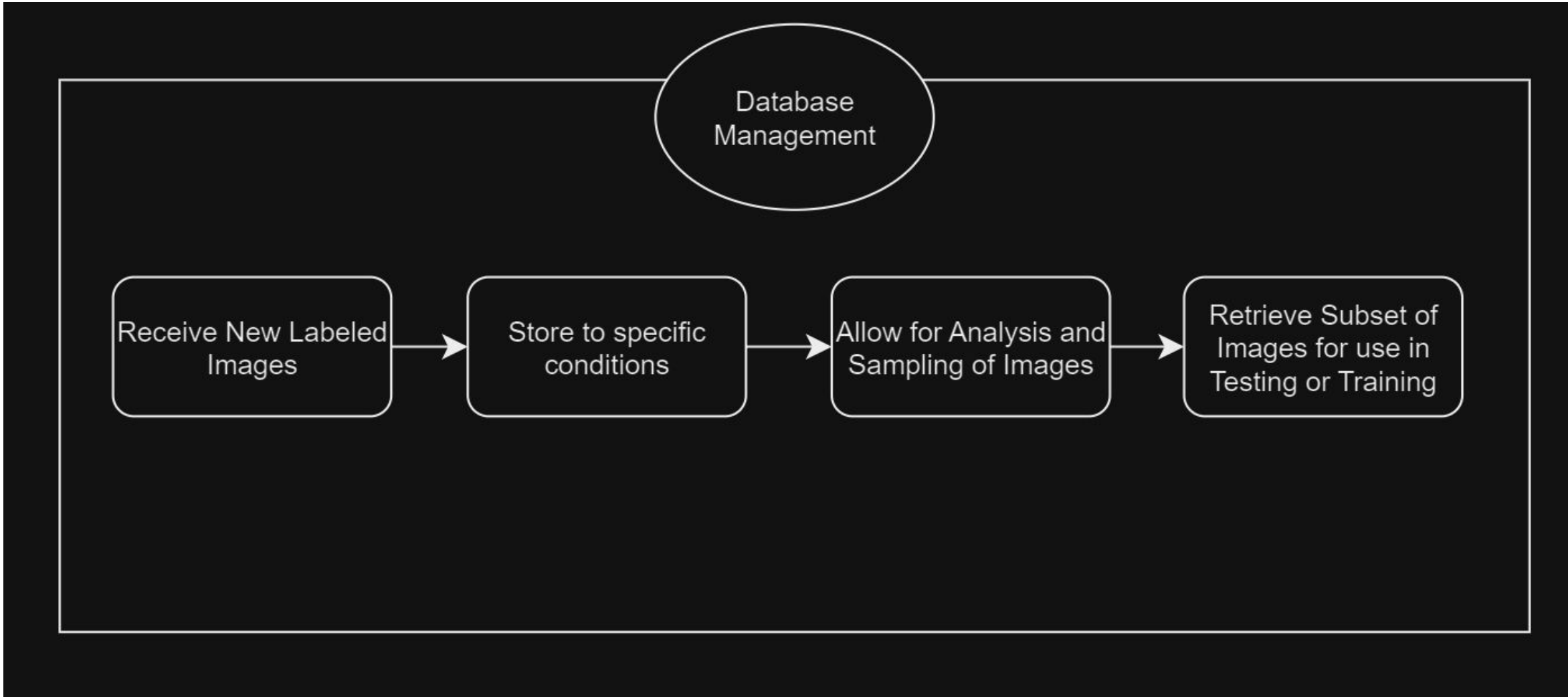
Module	Database Management
Inputs	Labeled Images
Outputs	Subsets of Labeled Images and Configuration files based on their form.
Functionality	Allow easy access and management of gathered labeled images for utilization in model training and analysis.

Functional Decomposition:



Functional Decomposition:

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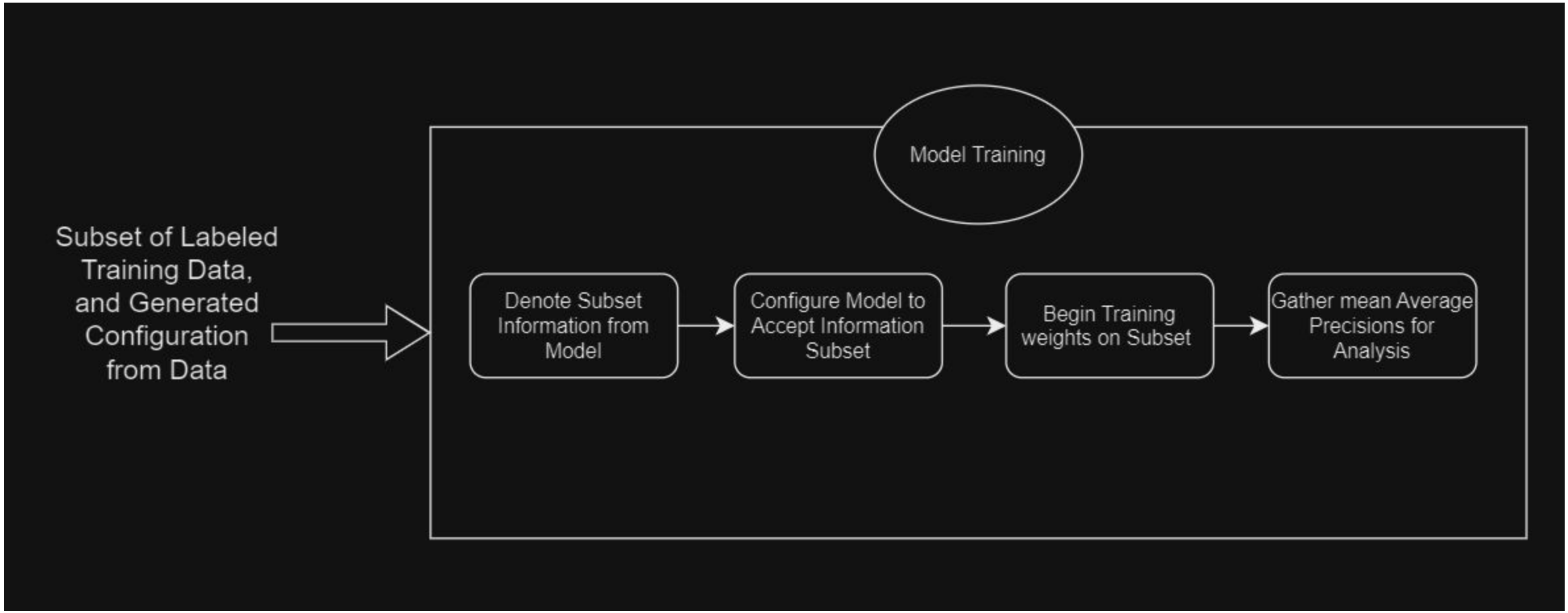
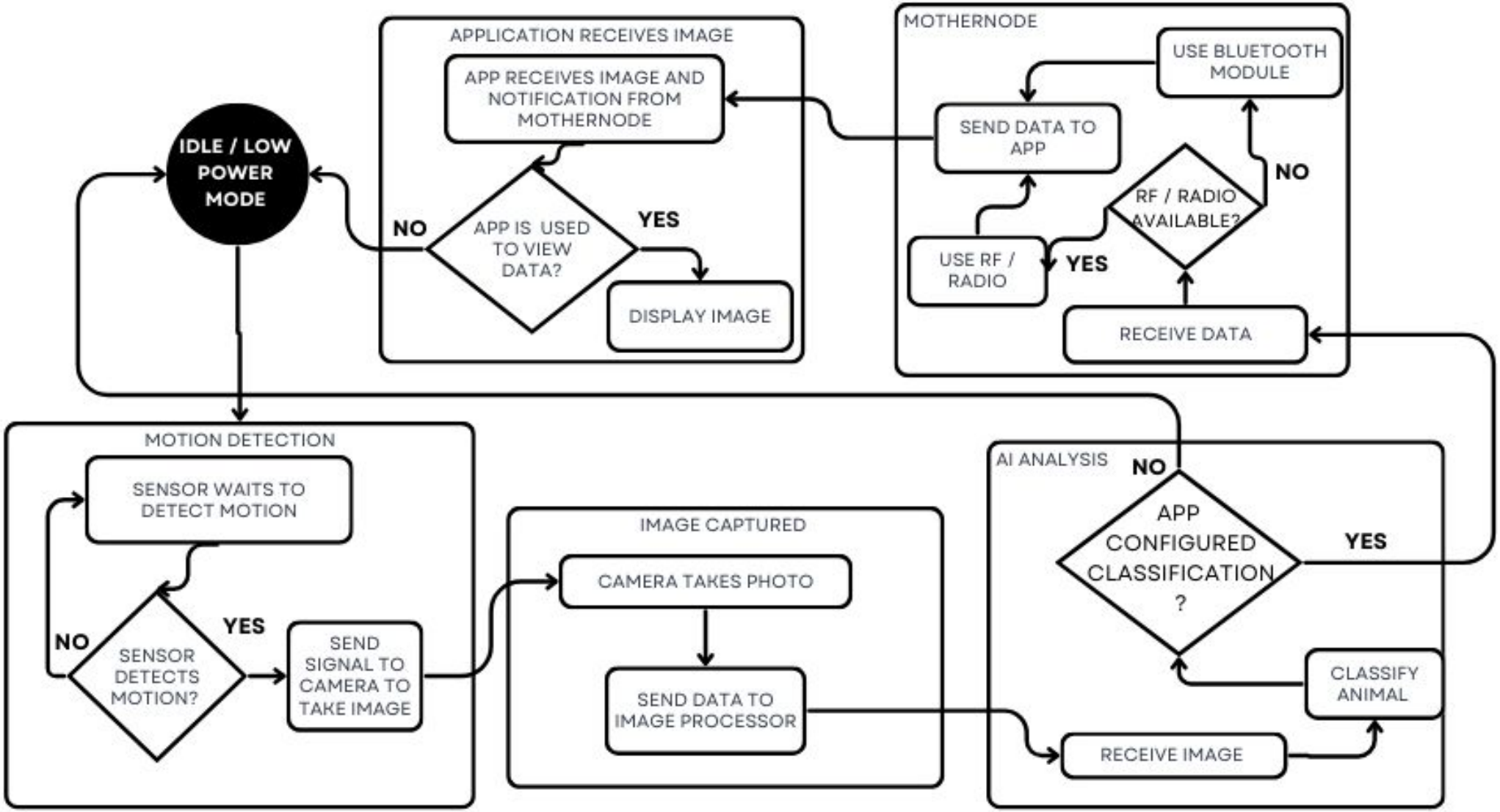
Module	Model Training
Inputs	Labeled Image Set and Configuration File Prior weights if applicable.
Outputs	Generated Weights, and Mean Average Precision (mAP)
Functionality	Weights are able to be loaded to edge devices for inference, and mAP provides information about performance of model.

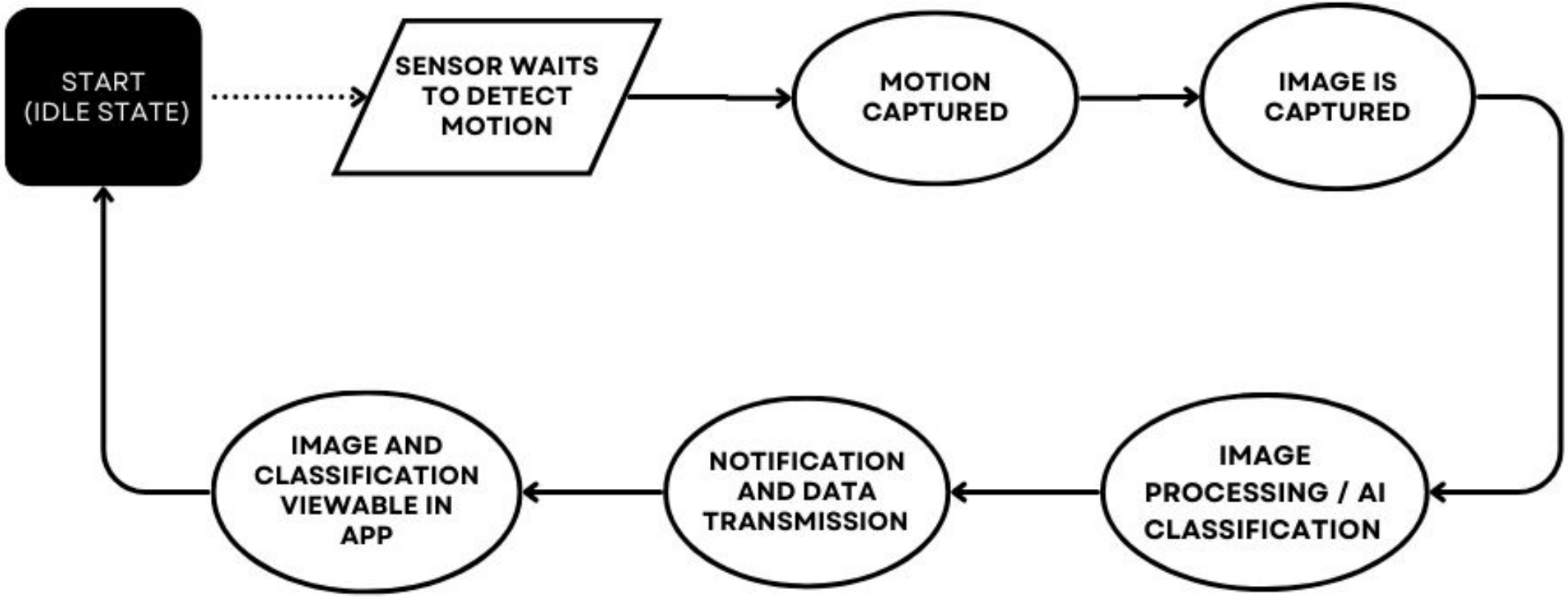
Functional Decomposition:



Behavioral Decomposition - State Machine



Behavioral Decomposition - Flowchart



Testing Plan - Unit Testing

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Motion Detection:

- **Objective**: Ensure that the camera activates within 0.8 seconds when motion is detected.
- **Test**: Simulate motion in front of the camera and measure activation time.
- **Expected Result**: Camera triggers within 0.8 seconds.

Animal Detection & Classification (ER1):

- **Objective**: Verify that the classifier accurately detects animals in images.
- **Test**: Feed test images of various animals (including false positives like inanimate objects) to the model and check classification, and classification accuracy.
- **Expected Result**: At least 50% accuracy across all animal types.

Battery Consumption (ER3):

- **Objective**: Ensure the camera can last for 30 days with average motion detection/triggers.
- **Test**: Simulate an average day of activity and monitor battery life then extrapolate.
- **Expected Result**: Battery lasts at least 30 days in low-power mode when idle and motion-activated when needed.

Testing Plan - Unit Testing cont.

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AI/ML Classification Analysis:

- **Objective**: Ensure that during the training process the AI/ML approach is able to classify various selected testing images.
- **Test**: Provide AI/ML with a set of images that the model has not seen in training before.
- **Expected Result**: AI/ML to classify the animals with the correct label.

AI/ML Realtime Computation:

- **Objective**: Ensure that during a real scenario, the AI/ML is able to produce outputs quick enough to be running at near real time speed.
- **Test**: Run AI/ML on expected hardware performing inference on various images and videos.
- **Expected Result**: AI/ML is able to produce classification output in near-realtime.

Testing Plan - Integration

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Motion Detection with Animal Classification:

- **Objective**: Test that when motion is detected, the camera captures the footage, processes the video/image, and identifies animals correctly.
- **Test**: Trigger motion and verify that the camera captures video/images and processes the classification in real-time.
- **Expected Result**: Motion activated camera, video is recorded, and classification is performed successfully.

Multiple Cameras/Nodes (ER5):

- **Objective**: Ensure that the app can handle simultaneous connections from at least four cameras.
- **Test**: Connect two-four nodes and trigger events from each. Verify that the app processes all incoming data.
- **Expected Result**: App correctly receives alerts from all cameras with minimal data loss or latency.

Battery Life with Motion Activation (ER3):

- **Objective**: Test that the motion detection and real-time processing don’t drain the battery prematurely.
- **Test**: Simulate field-like conditions over several days and measure battery consumption under normal use.
- **Expected Result**: The camera maintains sufficient battery for at least 30 days.

Testing Plan - Acceptance

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Full System Test in Field Conditions (ER1, ER3, ER4):

- **Objective**: Verify the entire system in field conditions, simulating real-world scenarios
- **Test**: Deploy cameras in the field for a 2-week period, simulating typical field conditions. Test app configurations, real-time alerts, battery life, and offline functionality.
- **Expected Result**: Cameras function correctly, providing accurate alerts, battery lasts through the test, and the system works without internet access.

Tamper-Proof App Interface (ER2):

- **Objective**: Ensure that the mobile app configuration settings are secure, and multiple cameras can be configured simultaneously without unauthorized access.
- **Test**: Attempt to tamper with app settings while verifying encryption and secure communication. Test camera configuration for all four cameras simultaneously.
- **Expected Result**: App settings are protected from tampering, and all cameras can be controlled without conflict or data loss.

Multi-Camera Management (ER5):

- **Objective**: Ensure that the app can manage and display alerts from multiple cameras at once.
- **Test**: Set up four cameras and verify that the app properly displays real-time alerts and direction of the source camera.
- **Expected Result**: The app correctly manages alerts from four cameras and displays the source of the alert.

Testing Plan - Failure Plan

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Unit Test Plan: If a unit test fails, immediately create a backlog of the bug. Assign priorities based on importance (e.g., battery life would be high priority). Slack time will be used for debugging and fixing issues. Re-run failed tests after fixes.

Integration Plan: If integration tests fail, assign bugs to the appropriate teams (e.g., hardware or software) and prioritize fixes. Use slack time to retest the integrated components.

Acceptance Plan: If any part of the acceptance test fails, re-assess the system requirements. Minor bugs will be logged and fixed in an additional sprint, but critical issues will trigger a full system review. Slack time is allotted for adjustments and retesting.

Gantt Chart: Fall Semester

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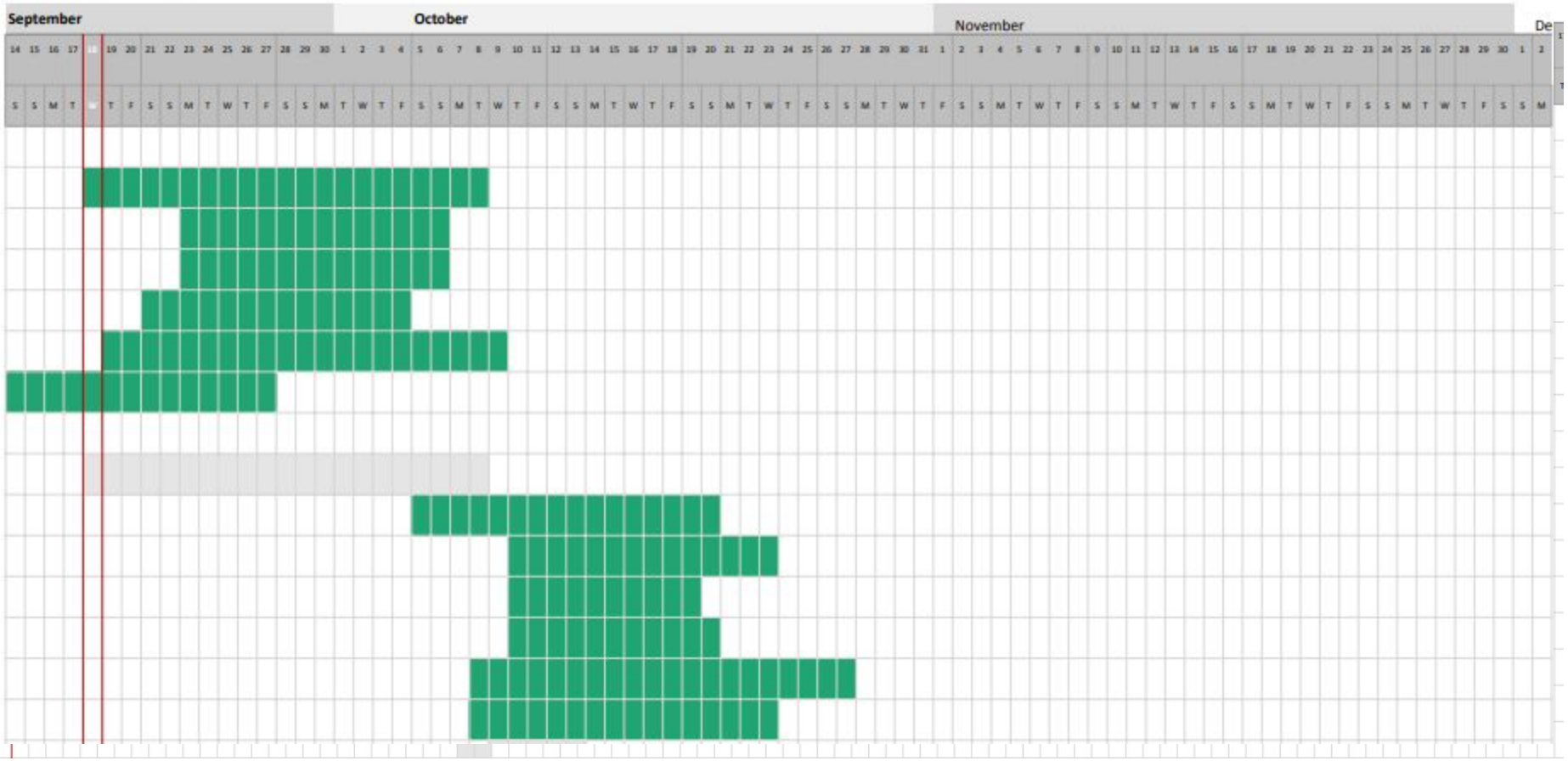
Fall Semester Smart Trail Cam

Group 10

Project start date: 9/14/2024

Legend: On track | Low risk | Med risk | High risk | Unassigned

Milestone description	Category	Assigned to	Progress	Start	Days
Initial Research					
Research Machine Learning/AI Approaches	On Track	Rio, Alyson	25%	9/18/2024	21
Research Necessary Security Components	On Track	All	0%	9/23/2024	14
Research Alert Systems for prototyping	On Track	Bobby, Tate	0%	9/23/2024	14
Research Mobile Application Development (Android)	On Track	Bobby, Alyson	0%	9/21/2024	14
Research Trail Cameras & Hardware	On Track	Rio, Tate	10%	9/19/2024	21
Research Network Connectivity	On Track	Rio, Tate	15%	9/14/2024	14
Design Phase					
Milestone Briefing (Oct. 9)		All	0%	9/18/2024	21
Mobile Application Design	On Track	Bobby, Alyson	0%	10/5/2024	16
Training Dataset Collection	On Track	Rio, Alyson	0%	10/10/2024	14
Dataset labeling	On Track	All	0%	10/10/2024	10
Database Design	On Track	Bobby, Alyson	0%	10/10/2024	11
Hardware & Prototype Design	On Track	Rio, Tate	0%	10/8/2024	20
Design Prototyping Network Connectivity	On Track	Rio, Tate	0%	10/8/2024	16



Gantt Chart: Fall Semester cont.

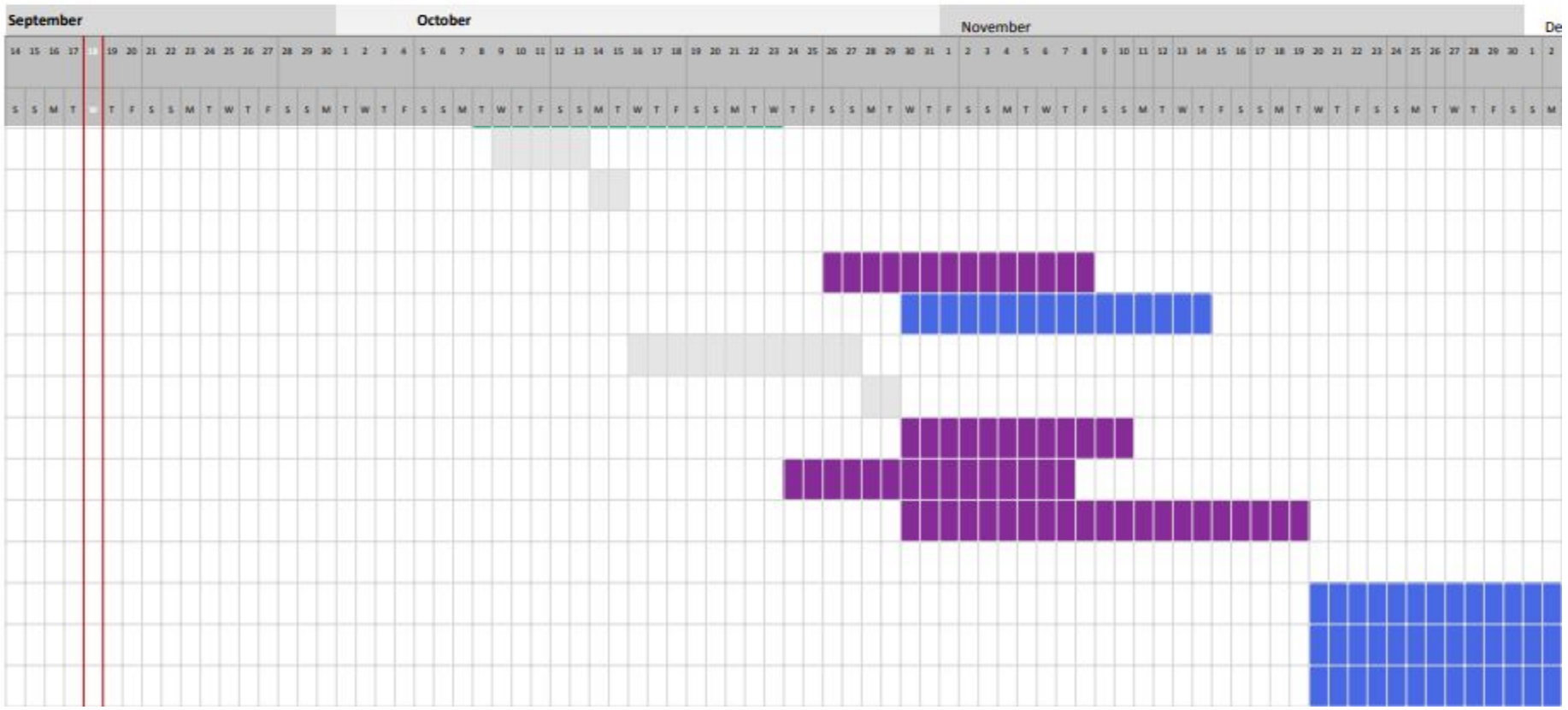
Fall Semester Smart Trail Cam

Group 10

Project start date: 9/14/2024

Legend: On track | Low risk | Med risk | High risk | Unassigned

Milestone description	Category	Assigned to	Progress	Start	Days
Milestone Briefing (Oct. 14)				10/9/2024	5
Milestone Briefing (Oct. 16)		All		10/14/2024	2
Development and Integration Phase of Prototypes					
Mobile Application Development	High Risk	Bobby, Alyson	0%	10/26/2024	14
Alert System Prototype Development	Med Risk	Bobby, Tate	0%	10/30/2024	16
Milestone Briefing (Oct. 28)		All	0%	10/16/2024	12
Milestone Briefing (Oct. 30)		All	0%	10/28/2024	2
Training Model on Labeled Dataset	High Risk	Rio, Alyson	0%	10/30/2024	12
Network Connectivity Development	High Risk	Rio	0%	10/24/2024	15
Hardware Development	High Risk	Rio, Tate	0%	10/30/2024	21
Testing and Validation Phase of Prototype					
Motion Sensor Unit Testing	Med Risk	Bobby	0%	11/20/2024	15
Animal Detection & Classification	Med Risk	Rio, Alyson	0%	11/20/2024	14
Closed Internal System Test	Med Risk	All	0%	11/20/2024	15



Gantt Chart: Spring Semester

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- Milestones:
  - Complete deliverables
    - Two or more fully functional nodes
    - Android phone/tablet with function application
    - Gitlab repository with all artifacts
- Focus:
  - Spend initial portion of the semester doing any additional research required
  - Continue design and development of hardware
  - Focus on full cybersecurity model and anti-tampering portions
  - Complete full-field testing with all components
  - Complete documentation and creation of artifacts for GitHub Repository.

Individual Responsibility

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- Responsibilities:
  - Mobile Application, Database, Cybersecurity - Bobby Calhoun
  - Hardware, Network Connectivity, Cybersecurity - Tate Forcella
  - Machine Learning/Dataset Training, Hardware, Cybersecurity - Rio Laney
  - Mobile Application, Machine Learning, Cybersecurity - Alyson Williams

- Contingency Plan:
  - Loss of a team member will result in a redistribution of workload where the remaining team members will split up the missing member's tasks. We will have at least two people on each task to ensure that at least one other member is familiar with the content.
  - If an event occurs where a lockdown is put into place, we will move into a fully remote work environment. For physical components, a meeting place will need to be decided or simulations will be conducted in their place.
  - In the event of weather conditions, our group will meet remotely and discuss how to proceed once conditions have lessened.

Parts - Cost Estimation cont.

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Compute Module
- 29$ - Grove Vision AI v2 Kit [1]

Radio/Network Connectivity
- 11$ 3x Wireless Transceiver Module, RF Transceiver Module, 2.4G 1100m [2]

Motion Sensor
- $24.95 - JemRF Wireless Motion sensor kit [3]

Estimated price for a development of a single node is ~150$

Additional component is an Android Phone/Tablet. A recent android phone is:

Samsung Galaxy A03s Cell Phone - 70$

1. https://www.seeedstudio.com/Grove-Vision-AI-V2-Kit-p-5852.html
2. https://www.amazon.com/Wireless-Transceiver-NRF24L01-Antenna-Raspberry/dp/B07QRZHZGY
3. https://www.jemrf.com/collections/rf-sensors/products/wireless-motion-sensor-kit
4. https://www.amazon.com/Samsung-Unlocked-Smartphone-Expandable-Infinite/dp/B09SM24S8C

Parts - Cost Estimation

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Camera
- 15-25$ - Raspberry Pi NoIR Camera Module V2 [1]
- 15$ - Bright Pi [2]

LED
- 3.5$ (7$) - 2x Infrared LED Light Board Module [3]

Battery
- 20$ - Portable Charger Power Bank 30000mAh [4]

SoC
- 55$ - Raspberry Pi 4 Model B 4GB / Board Only [5]

1. https://www.pishop.us/product/raspberry-pi-noir-camera-module-v2/?src=raspberrypi
2. https://www.pishop.us/product/bright-pi-bright-white-and-ir-camera-light-for-raspberry-pi/
3. https://www.amazon.com/Infrared-Illuminator-Adjustable-Resistor-Raspberry/dp/B07FM6LL3V
4. https://www.amazon.com/Portable-Charger-Power-Bank-30000mAh/dp/B0CDLMKN35
5. https://vilros.com/products/raspberry-pi-4-model-b-1?src=raspberrypi

Cost Estimation

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- We expect the University of Alabama in Huntsville to pay for the necessary materials needed to complete this project.

- Fixed:
  - Camera, Motion sensor, battery, microcontroller, android device, transceiver module

- Variable:
  - No costs will vary throughout the project duration

- Labor:
  - 40-60 hours a week, 10-15 per group member

Resources and Deliverables

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- Resources
  - Camera
  - Motion sensor
  - Network Transceiver
  - Battery
  - SoC/Microcontroller
  - Android Device
- Report
  - Field Test Results
  - Gitlab Artifact
  - Database of Labeled Training Set
  - Classification Accuracy Report for Each Wildlife Category
- Deliverables
  - Hardware
    - Smart Trail Camera
    - Alert System Prototype
  - Software
    - Mobile App Interface
    - Gitlab Repository with artifacts

CPE495/496 Milestones

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- CPE 495 Milestones:
  - Background research over:
    - Machine Learning, Hardware, Database creation, Mobile application development
  - Project Proposal
  - Begin Design of hardware, application, network
  - Initial Design Review
  - Development of Application and Prototype
  - Final Report

- CPE 496 Milestones:
  - Continue development of hardware, connections, cybersecurity component
  - Project Status Meeting
  - Conduct testing and documentation for all artifacts
  - Final Design Reviews

Abstract

The Smart Trail Cam (STC) is an animal aware trail camera that performs classification, analysis, and alerting of detected animals. It incorporates multiple edge nodes to perform monitoring, and a 'mother' node to provide an interop between these edge nodes and an Android application which receives these analysis's and alerts to showcase to the user. Furthermore, the STC Android application allows configuration of edge nodes through selection of critical animal classification alerts, location, and battery life.

Appendix

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Engineering Requirements - Full List	
ER1	Animal classification with 50% accuracy against separate specifically chosen testing data.
ER2	Animal classification in wild with 25% accuracy in environments with proper setup, and lighting.
ER3	Secure and encrypted multi-camera connection and configuration within app interface.
ER4	30 Day battery life under average daily load (4% active computation in a day).
ER5	Activation of SoC within 0.8 seconds of Motion Detection.
ER6	Connectivity with up to a 25-meter (~90 feet) range.
ER7	Simultaneous multi-camera connections without data loss.
ER8	Real-time alerts indicating the camera's location within 6 seconds.

Appendix

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Engineering Requirements - Continued	
ER9	Connectivity for up to four trail cameras
ER10	Classification data covers at least 4 animals including but not limited to squirrels, cats, dogs, and birds
ER11	Application will support at least one priority notification which allows the user to get notifications of one specific creature
ER12	Trail camera will function independently of network access and will store up to 20 images while connection is unavailable
ER13	Application will maintain a log of alerts, timestamps, and identified animal

Questions

- We are now open to any questions