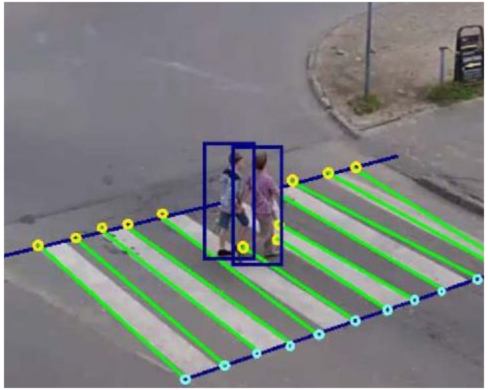
Use Case + Use Case Requirements

CHALLENGE: Visually impaired pedestrians rely on external aids to cross the road.

- Not all crossroads have reliable or maintained aids
- Obstacles (like debris) on the road can further reduce safety

SOLUTION: A head-worn device that aids the user in crossing the road by providing real time visual-to-audio guidance.

- “WALK” vs. “DON’T WALK” signals
- Helps user stay within the crosswalk
- Alerts to unexpected objects in the walking path



Quantitative Design Requirements - Hardware

Use Case Requirement	Design Requirement	Why
Detect walk signs and obstacles in real-time to guide user	IMX219 wide-angle camera: 1920x1080@30fps, 105° FOV	105° FOV is wide enough to see objects around user 1920x1080 is high enough resolution for model
Keep user within ±20° of the correct crosswalk alignment	BNO055 IMU with heading accuracy of ±2°	Extremely precise IMU, and accounts for things like head tilt.
Provide real-time audio feedback within 0.5s of creating navigation event	USB sound card + on-ear headphones (<0.01s hardware latency)	On-ear headphones give better environmental awareness
Device must last ≥ 2 hrs on battery	10,000 mAh power bank with DC barrel jack adaptor	Jetson Orin Nano draws 7-15W depending on power mode. (15W * 2hrs * 1000)/5V = 6,000mAh

Quantitative Design Requirements - Software

Use Case Requirement	Design Requirement	Why
The system must correctly classify the walk signal with AUROC ≥ 0.9 to ensure high reliability.	Walk Sign Classification model must achieve AUROC > 0.9 on the test set.	Ensures the model is robust enough for real-world usage, balancing accuracy with computational feasibility while maximizing user safety.
The probability of misclassifying the walk signal over 5 consecutive frames should be < 1%.	Majority voting: The model must correctly classify at least 90% of individual frames to ensure that the probability of 3/5 consecutive frames being misclassified is < 1%.	Reduces the impact of individual frame misclassifications, improving system robustness and user trust in the guidance system.
The system must provide a decision within 3 seconds to allow users to react to a "GO" signal.	Model inference latency must be ≤ 3 sec per frame.	Ensures that users receive timely guidance, preventing delays that could impact safe crossing decisions.

Quantitative Design Requirements - Software

Use Case Requirement	Design Requirement	Why
The system must detect obstacles with at least 90% accuracy to ensure user safety.	Computer Vision Model (YOLOv8) must achieve ≥ 70% mAP (mean Average Precision)	Ensures that the model detects obstacles with high reliability while balancing computational constraints. Higher mAP improves real-world detection accuracy and user safety.
The system must correctly classify the walk signal in at least 90% of frames to provide reliable guidance	Majority voting: The system must correctly classify at least 90% of individual frames, ensuring that the probability of 3/5 consecutive frames being misclassified is <1%.	Majority voting increases system robustness, reducing the chance of a critical false negative. This ensures reliable obstacle detection even under varying conditions.
The system must provide feedback within 1.5 seconds to allow users enough time to react.	Model inference latency must be ≤ 1 sec per frame.	A low latency ensures that the user receives timely warnings and has sufficient reaction time to avoid obstacles.

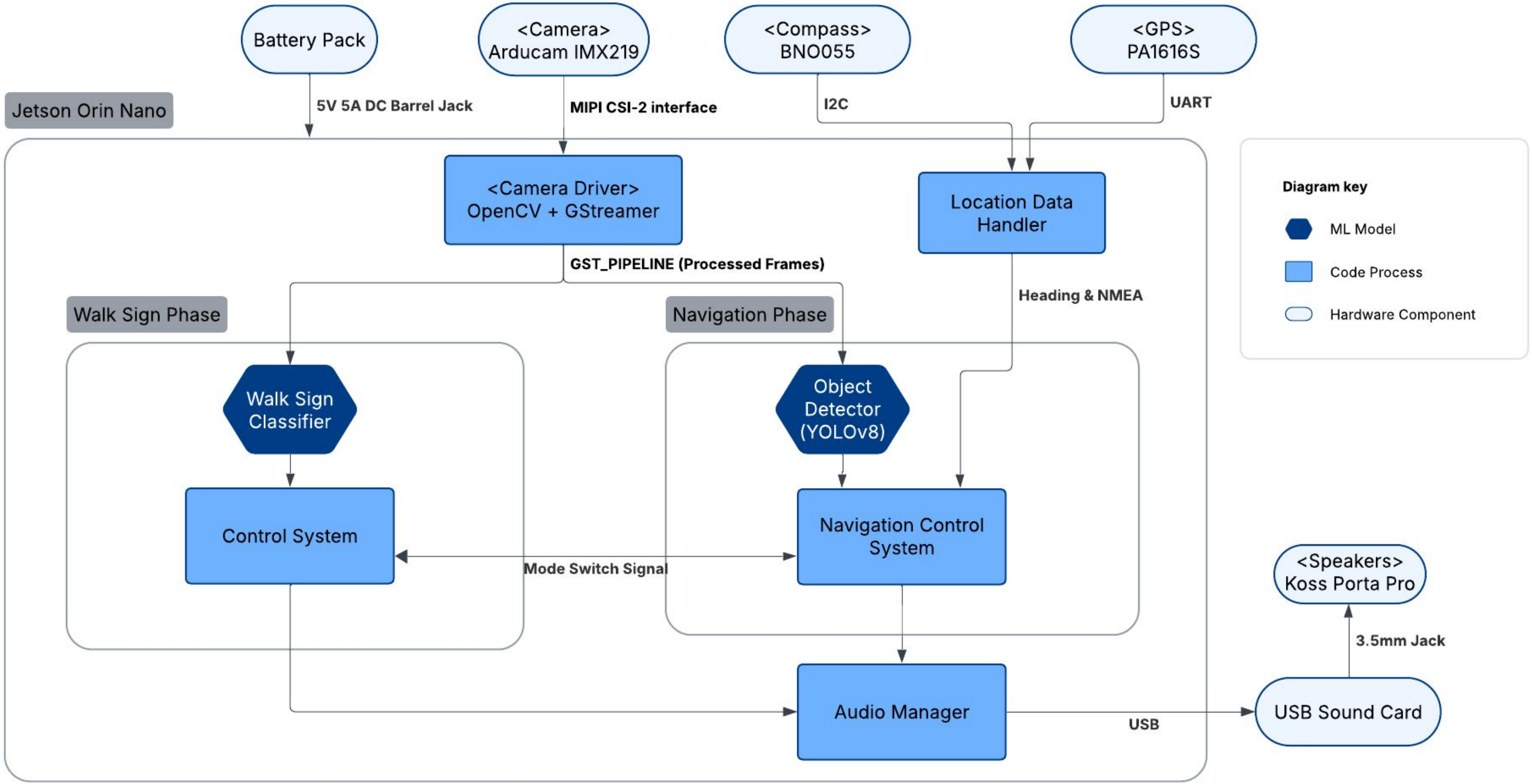
Quantitative Design Requirements - Software

Use Case Requirement	Design Requirement	Why
Crosswalk navigation allows for no more than 20 degrees of deviation	ML model and/or GPS must detect deviations ≥ 20° with at least 90% accuracy.	Ensures users maintain a safe and effective walking path while allowing for natural movement.
The system must provide corrective audio feedback within 1 second of detecting veering, clarity of feedback should be satisfactory as per the user	Audio feedback system (e.g., using pyttsx3) must generate a response within ≤ 1 sec of deviation detection. Audio feedback must be tested for clarity and comprehension, with at least 90% user satisfaction in trials.	Timely feedback is essential to help users correct their trajectory before veering too far off course., while unclear or confusing feedback can be as harmful as delayed feedback for visually impaired users.

Solution Approach

- How We Are Solving the Problem:
  - Real-time ML on Jetson Orin Nano
  - Camera based identification
  - GPS based compass for alignment
  - Audio Feedback
- Evolution Since Proposal:
  - Compass + GPS
  - USB Sound Card
- Considerations:
  - Avoids reliance on inconsistent infrastructure
  - Promotes self sufficiency

System Specification



Implementation Plan - Part 1

<u>Designing \ Developing:</u>

- Walk Sign Classifier + Control System
- Navigation Control System
- Camera Driver
- Location Data Handler
- Audio Manager
- Labelled datasets

<u>Buying:</u>

- Jetson Orin Nano
- Arducam IMX219
- BNO055 IMU
- Power Bank
- Headphones
- Helmet

<u>Assembling:</u>

- Mounting
- Cases

Implementation Plan - Part 2

<u>Copying:</u>

- Neural Network Architecture for Walk Sign Image Classifier
- Object Detector (YOLOv8 Model)
- Portions of datasets

<u>Downloading:</u>

- Hardware drivers
- Libraries

Testing, Verification and Metrics - Part 1

Test Name	Test Inputs	Test Outputs	Passing Criteria	**Risk**/*Mitigation*
Per-frame Classification Performance	Real-world video frames from crosswalks under various lighting and weather conditions.	AUROC (Walk SIgn Classification) mAP (Object Detection)	AUROC > 0.9 mAP > 0.7	**Low accuracy in poor visibility** *Retrain model with nighttime and foggy data.*
Majority Vote Classification Accuracy	10-frame sequences from test dataset.	Accuracy: Correct majority vote predictions/Total number of sequences	≥ 95% accuracy across test sequences.	**Model inconsistencies across frames** *Implement smoothing techniques.*
Inference & Audio Response Time	Measure processing time for 10-frame inference batches and audio playback delay.	Inference time per frame and batch; audio delay.	Inference latency ≤ 100ms/frame; audio delay ≤ 500ms.	**High latency issues** *Optimize model through quantization*
User Verification	Users wear system and attempt to detect walk signals and obstacles.	% of users successfully orienting camera to detect signals.	≥ 95% success rate within 5s.	**Users struggle with alignment** *Improve mounting instructions or add auditory guidance.*

Testing, Verification and Metrics - Part 2

Test Name	Test Inputs	Test Outputs	Passing Criteria	**Risk**/*Mitigation*
Veering Angle Detection	Controlled user tests walking along a straight path and at predefined angles (10°, 20°, 30°).	Correctly detecting 20°+ deviations/All 20°+ deviations	≥ 95% accuracy for 20°+ deviations.	**Failure to detect** *Adjust detection thresholds or refine sensor placement.*
Audio Response Time	Users simulate veering (>20°); measure delay from detection to audio.	Mean delay (ms).	≤ 300ms response time.	**Delayed feedback** *Optimize sensor-to-audio processing pipeline.*
Audio Feedback Clarity	Users intentionally veer off-course and provide subjective ratings.	Clarity score (1–5 scale).	Mean clarity rating ≥ 4.0	**Poor clarity** *Improve phrasing, volume, or sound cues.*
Power Draw Test	Measure device power consumption under maximum load.	Battery life (hours) at peak wattage.	≥ 6 hours of operation.	**High power consumption** *Optimize power management and low-power states.*

Project Management