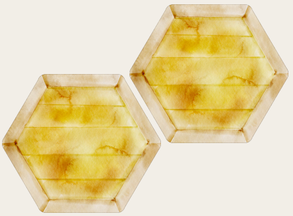

BeeGuardAI : Embedded system for detecting Asian hornets and monitoring bee activity using AI

2025/2026

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THEME: Embedded system for detecting Asian hornets and monitoring bee activity using AI

PROBLEM STATEMENT

CONTEXT:

BEE COLONIES ARE ESSENTIAL FOR POLLINATION BUT ARE THREATENED BY THE ASIAN HORNET (VESPA VELUTINA).

CURRENT CHALLENGES:

- REPEATED HORNET ATTACKS ON HIVES
- PROGRESSIVE WEAKENING OF COLONIES
- DIFFICULTY IN CONTINUOUS MONITORING
- LATE DETECTION OF THREATS

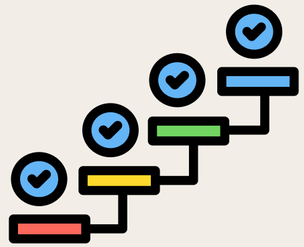
SOLUTION

HOW WE SOLVE THE PROBLEM:

BEEGUARDAI IS AN AUTONOMOUS EMBEDDED SYSTEM COMBINING COMPUTER VISION AND AUDIO ANALYSIS POWERED BY TINYML TO MONITOR BEEHIVES 24/7. THE SYSTEM DETECTS ASIAN HORNETS, TRACKS BEE TRAFFIC, AND ANALYZES COLONY HEALTH THROUGH ACOUSTIC PATTERNS, PROVIDING REAL-TIME ALERTS TO BEEKEEPERS.

HOW IT HELPS SOLVE THE PROBLEM:

- EARLY DETECTION OF HORNET ATTACKS BEFORE COLONY DAMAGE
- CONTINUOUS MONITORING WITHOUT MANUAL INTERVENTION
- DATA-DRIVEN INSIGHTS FOR PROACTIVE COLONY MANAGEMENT
- REMOTE ACCESS VIA WEB DASHBOARD FOR MULTIPLE HIVES



IMPACT METRICS:

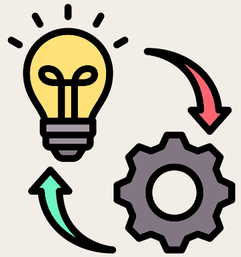
- HORNET DETECTION ACCURACY (TARGET: >90%)
- BEE COUNTING PRECISION (IN/OUT TRAFFIC PER HOUR)
- COLONY HEALTH STATUS CLASSIFICATION ACCURACY
- RESPONSE TIME FROM THREAT DETECTION TO ALERT (<5 MINUTES)
- SYSTEM UPTIME AND BATTERY AUTONOMY

SOLUTION

TECHNOLOGY STACK:

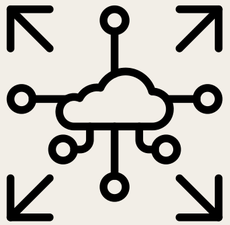
- HARDWARE: ESP32-CAM, ARDUINO NICLA VISION, MICROPHONES
- AI FRAMEWORK: EDGE IMPULSE (TINYML OPTIMIZATION)
- MODELS: YOLO-BASED OBJECT DETECTION, CNN/RNN FOR AUDIO CLASSIFICATION
- COMMUNICATION: LORAWAN (LOW POWER, LONG RANGE)
- BACKEND: INFLUXDB, NODE-RED / GRAFANA
- REASON: TINYML ENABLES ON-DEVICE INFERENCE WITH MINIMAL POWER CONSUMPTION; LORAWAN PROVIDES RELIABLE CONNECTIVITY IN REMOTE LOCATIONS

IMPLEMENTATION & EFFECTIVENESS:



- EASY DEPLOYMENT: MODULAR DESIGN ATTACHABLE TO ANY HIVE
- LOW COST: OPEN-SOURCE SOFTWARE + AFFORDABLE HARDWARE (<€150/UNIT)
- PROVEN TECHNOLOGY: TINYML SUCCESSFULLY USED IN WILDLIFE MONITORING

SCALABILITY/USABILITY:



- SCALABLE TO NETWORKS OF 100+ CONNECTED HIVES
- MULTI-USER DASHBOARD FOR APICULTURE COOPERATIVES
- ADAPTABLE TO OTHER PEST DETECTION SCENARIOS

THREAT RESPONSE SYSTEMS

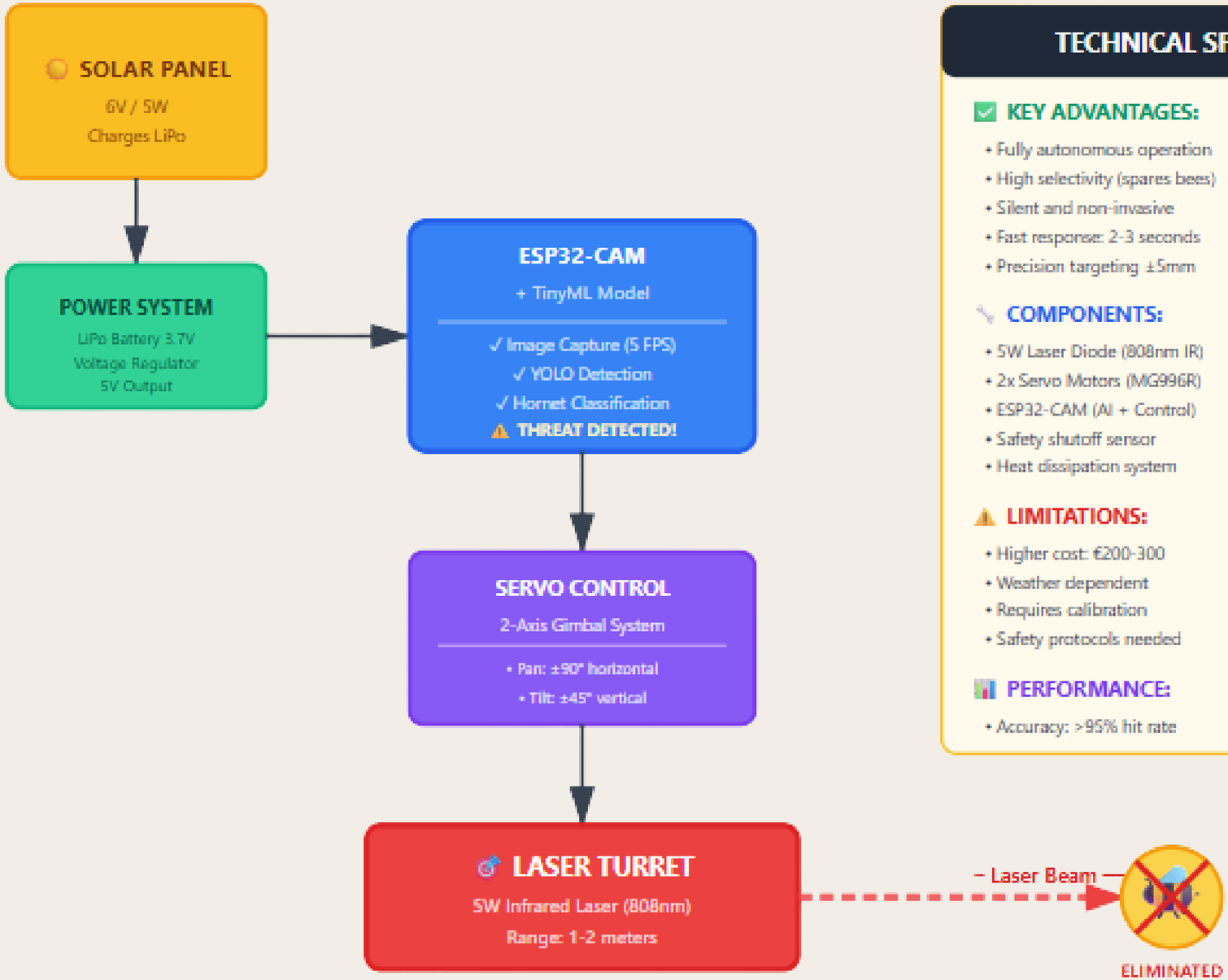
AUTOMATED ELIMINATION SOLUTIONS

ONCE ASIAN HORNETS ARE DETECTED BY THE AI SYSTEM, TWO RESPONSE MECHANISMS CAN BE ACTIVATED TO PROTECT THE COLONY:

SOLUTION 1: LASER-BASED ELIMINATION
→ HIGH-PRECISION TARGETING SYSTEM
→ AUTONOMOUS OPERATION
→ IDEAL FOR PROFESSIONAL APIARIES

SOLUTION 2: AUTOMATED ELECTRIC RACKET
→ CONTACT-BASED ELIMINATION
→ COST-EFFECTIVE SOLUTION
→ SUITABLE FOR HOBBYIST BEEKEEPERS

BOTH SYSTEMS INTEGRATE SEAMLESSLY WITH THE BEEGUARDAI DETECTION PLATFORM AND PROVIDE REAL-TIME ALERTS VIA THE DASHBOARD.



TECHNICAL SPECIFICATIONS

✅ KEY ADVANTAGES:

- Fully autonomous operation
- High selectivity (spares bees)
- Silent and non-invasive
- Fast response: 2-3 seconds
- Precision targeting ±5mm

🔧 COMPONENTS:

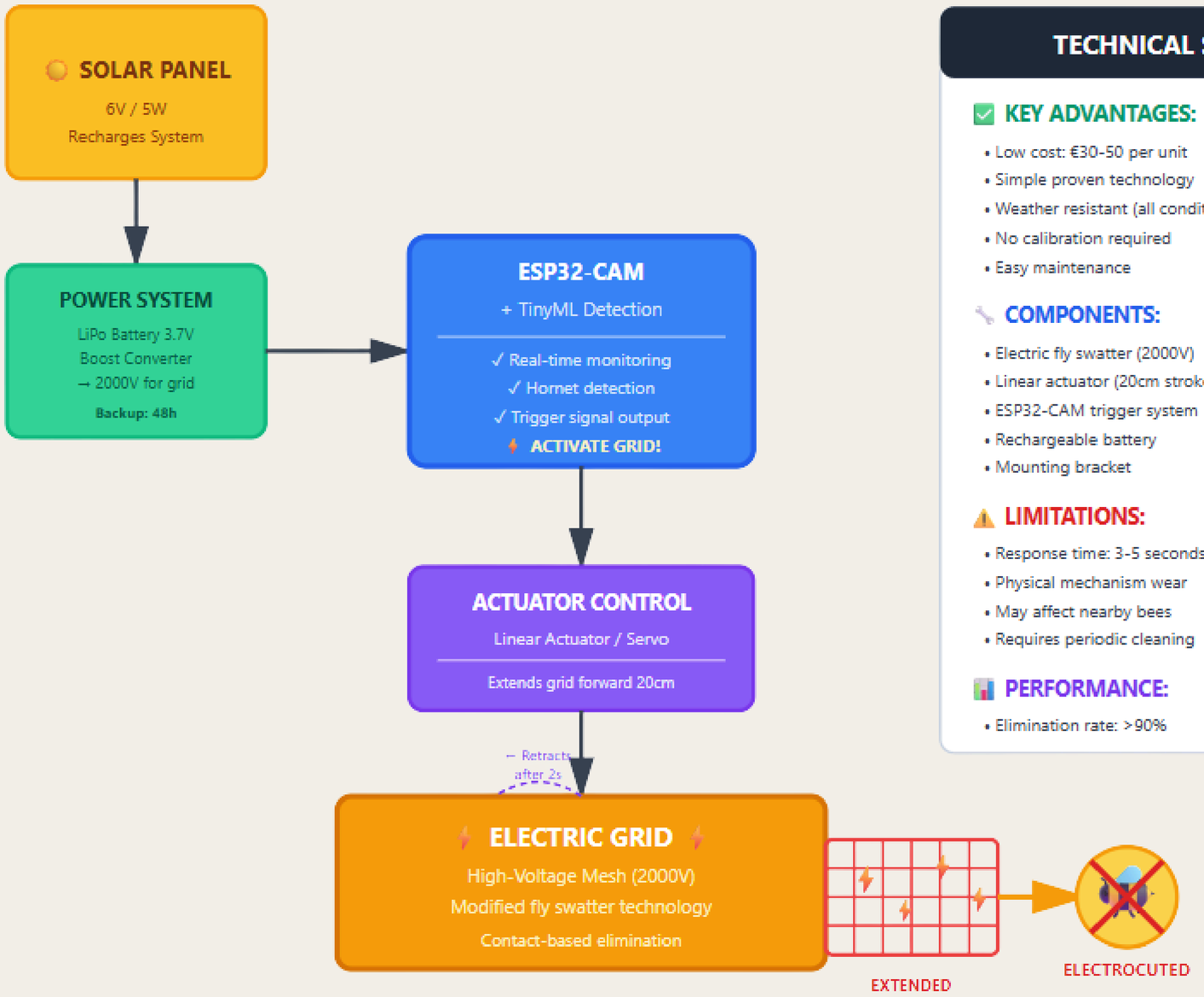
- 5W Laser Diode (808nm IR)
- 2x Servo Motors (MG996R)
- ESP32-CAM (AI + Control)
- Safety shutoff sensor
- Heat dissipation system

⚠️ LIMITATIONS:

- Higher cost: €200-300
- Weather dependent
- Requires calibration
- Safety protocols needed

📊 PERFORMANCE:

- Accuracy: >95% hit rate



TECHNICAL SPECIFICATIONS

✅ KEY ADVANTAGES:

- Low cost: €30-50 per unit
- Simple proven technology
- Weather resistant (all conditions)
- No calibration required
- Easy maintenance

🔧 COMPONENTS:

- Electric fly swatter (2000V)
- Linear actuator (20cm stroke)
- ESP32-CAM trigger system
- Rechargeable battery
- Mounting bracket

⚠️ LIMITATIONS:

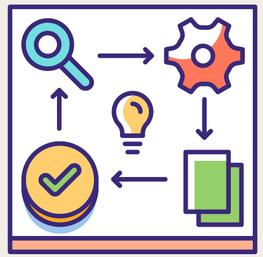
- Response time: 3-5 seconds
- Physical mechanism wear
- May affect nearby bees
- Requires periodic cleaning

📊 PERFORMANCE:

- Elimination rate: >90%

METHODOLOGY

CONCEPTS & PRINCIPLES:

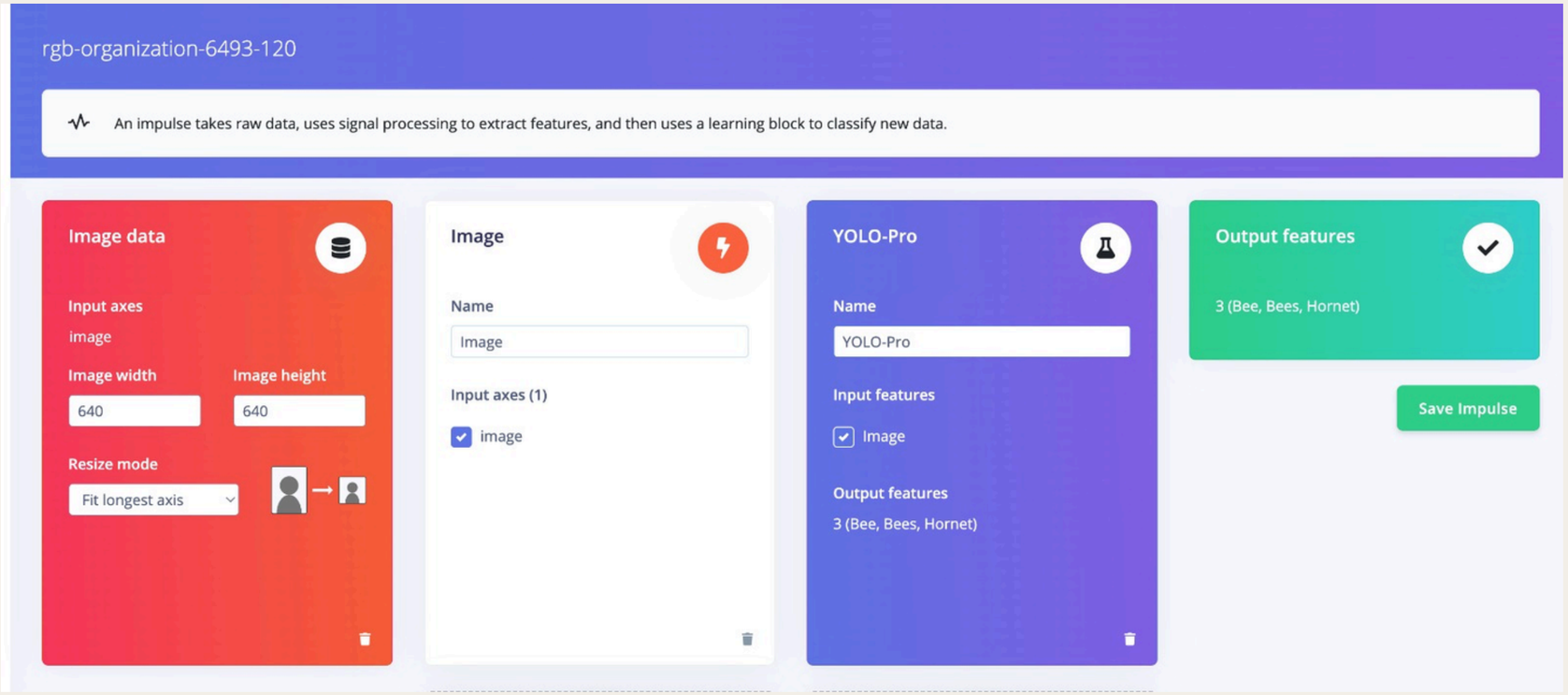


- EDGE COMPUTING: AI INFERENCE ON-DEVICE TO MINIMIZE LATENCY AND BANDWIDTH
- MULTI-MODAL SENSING: COMBINING VISION + AUDIO FOR ROBUST DETECTION
- LOW-POWER IOT: LORAWAN FOR ENERGY-EFFICIENT LONG-RANGE COMMUNICATION
- EVENT-DRIVEN ARCHITECTURE: SYSTEM ACTIVATES ON MOTION/SOUND TRIGGERS

SYSTEM COMPONENTS:

1. DATA ACQUISITION LAYER
   - ESP32-CAM (320X240PX IMAGES, 5 FPS)
   - PDM/I2S MICROPHONES (16KHZ SAMPLING)
   - ENVIRONMENTAL SENSORS (TEMPERATURE, HUMIDITY)
2. PROCESSING LAYER
   - VISION PIPELINE: IMAGE PREPROCESSING → YOLO DETECTION → CLASSIFICATION
   - AUDIO PIPELINE: MFCC FEATURE EXTRACTION → CNN CLASSIFIER → HEALTH STATUS
   - TINYML MODELS (<200KB) OPTIMIZED FOR ESP32
3. COMMUNICATION LAYER
   - LORAWAN GATEWAY (868 MHZ EU BAND)
   - PAYLOAD: DETECTION COUNTS + TIMESTAMPS (12 BYTES/MESSAGE)
   - TRANSMISSION FREQUENCY: EVERY 15 MINUTES OR ON ALERT
4. APPLICATION LAYER
   - TIME-SERIES DATABASE (INFLUXDB)
   - DASHBOARD (GRAFANA/NODE-RED) WITH REAL-TIME CHARTS
   - ALERT SYSTEM (EMAIL/SMS NOTIFICATIONS)

Edge Impulse Pipeline Configuration



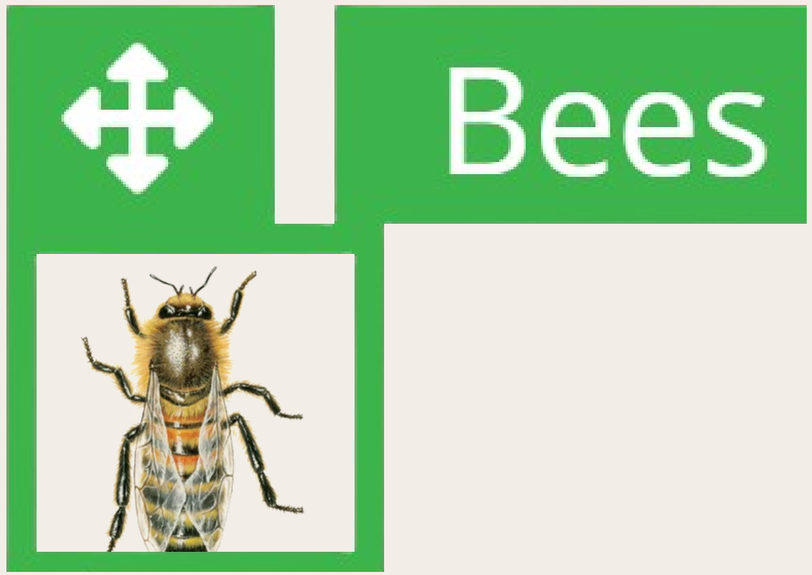
PIPELINE OVERVIEW:

- Image Input: 640x640px, resized to fit longest axis
- Feature Extraction: Image processing block for object detection
- Model: YOLO-Pro neural network
- Output: 3 classes (Bee, Bees, Hornet)

AI labeling

Labeling with bounding boxes

2 classes



AI labeling

Labeling steps :

Creation of bouding boxes (OWL-Vit object detector)

Boxes re-labeling (GPT-4o)

AI labeling

Comparison :

Ground truth (manual labeling)

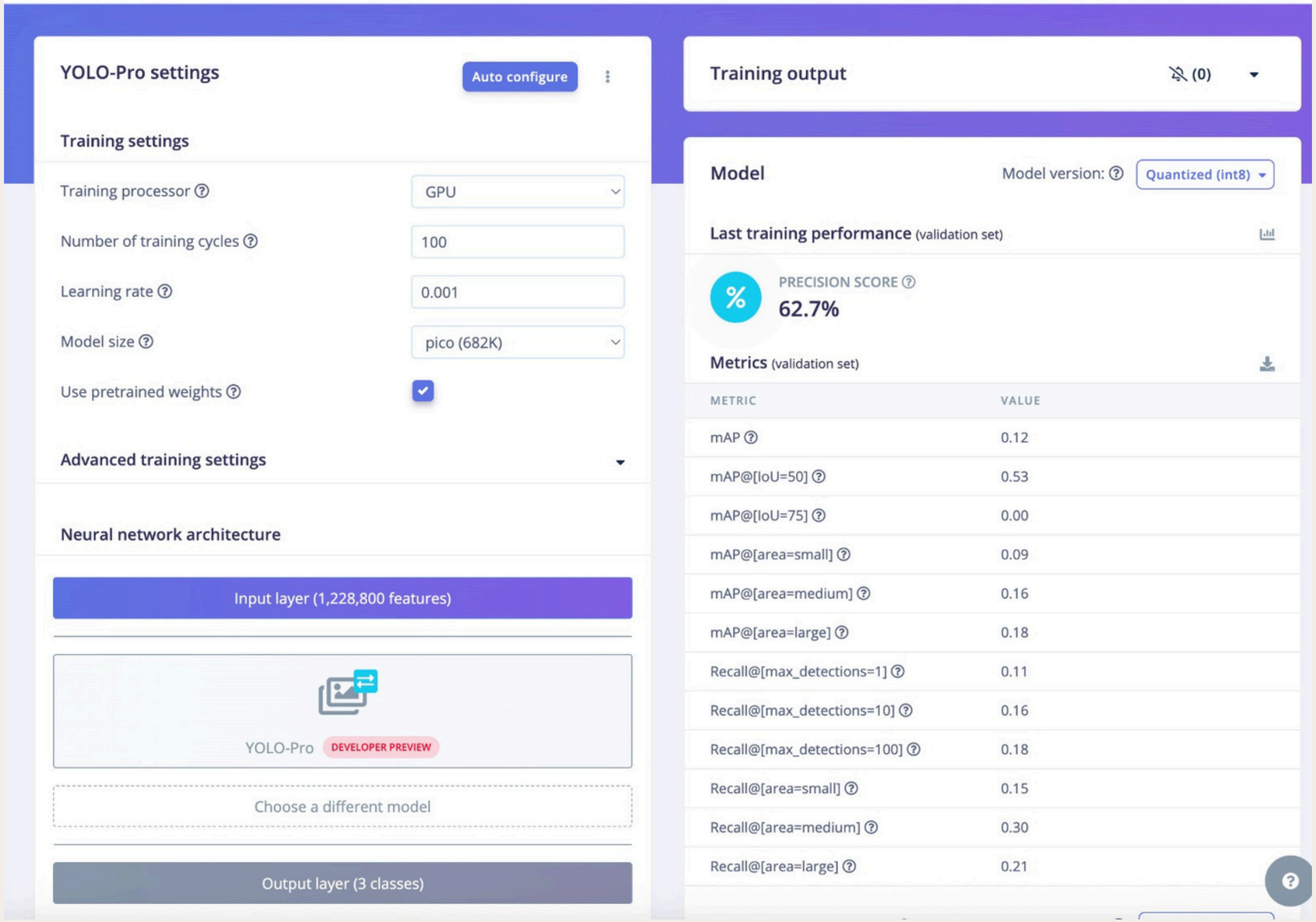
VS

Labeling using AI

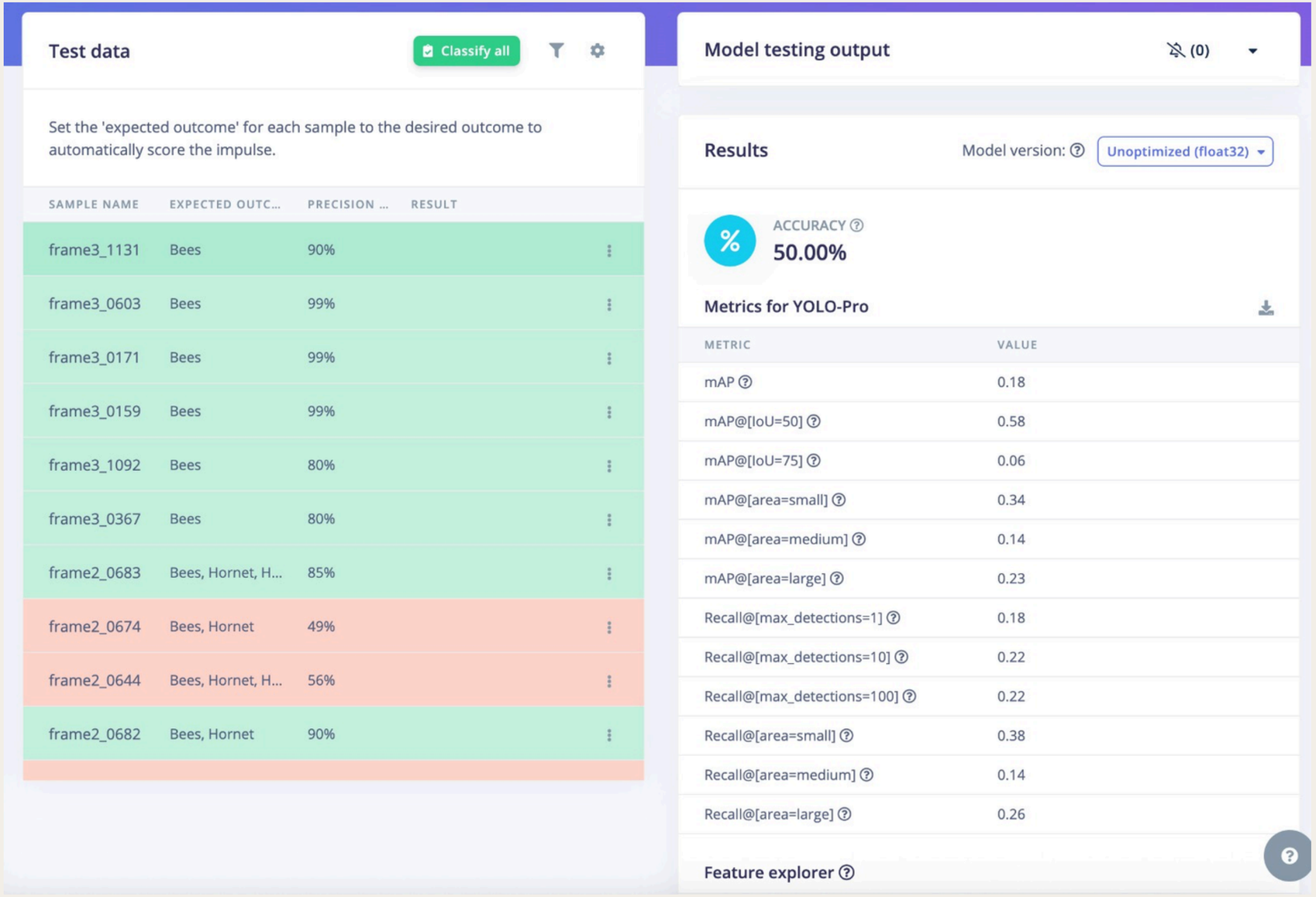
Analysis & Visualization

YOLO-Pro Training Configuration

YOLO-Pro model training parameters: 100 cycles, 0.001 learning rate, GPU, with pretrained weights. The model achieves a precision score of 62.7% on the validation set with an mAP of 0.12



YOLO-Pro Test Results

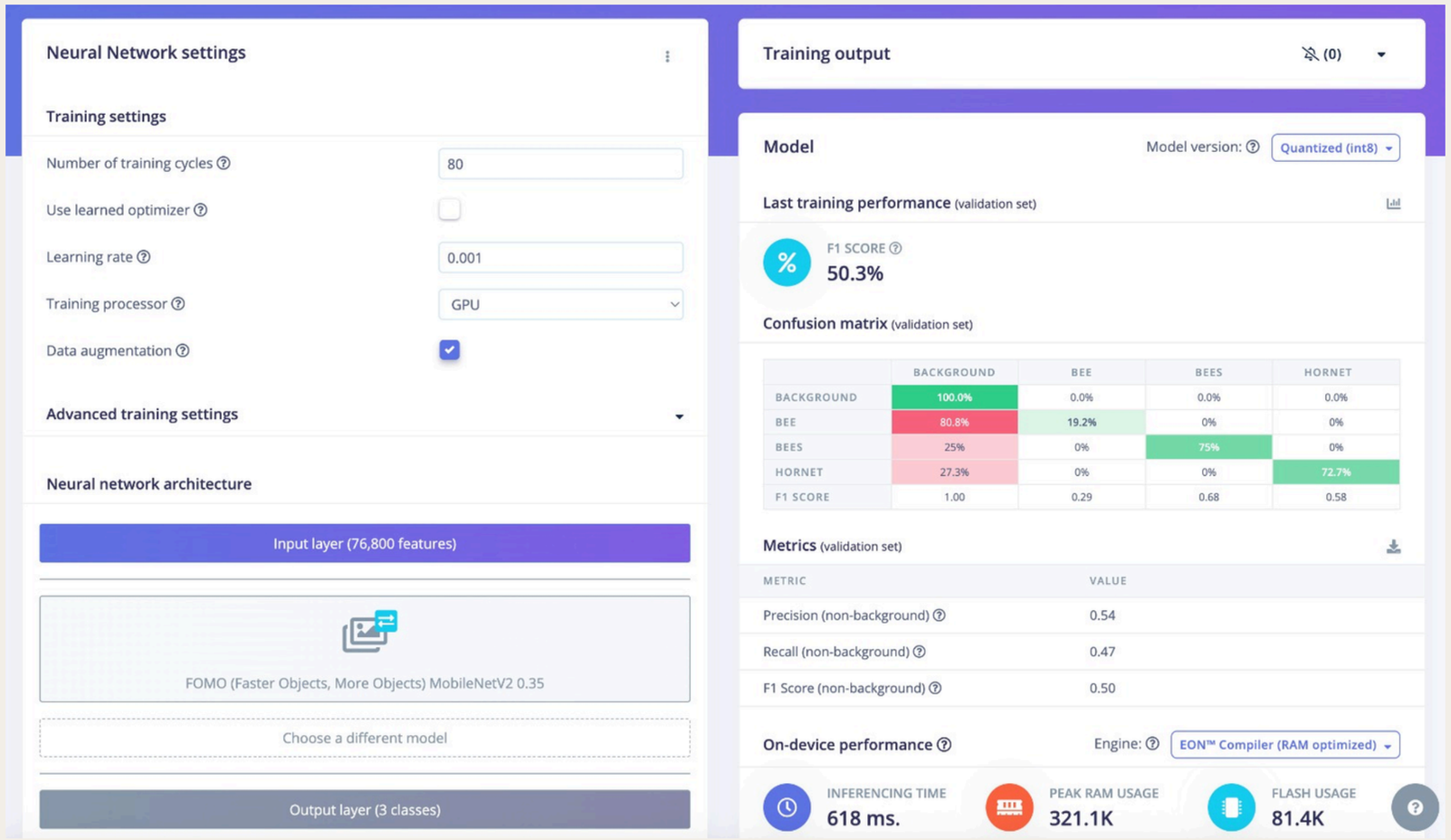


Validation results on the test set showing 50.00% accuracy with a mAP of 0.18. Detailed metrics display performance per class and object size.

Model Comparison with Different Latencies

NAME	INPUT	DSP BLOCKS	LEARN BLOCKS	F32_V_ACC	F32_T_ACC	I8_V_ACC	I8_T_ACC	F32_LATENCY	F32_RAM	F32_FLASH	I8_LATENCY
Image detection model 2	160×160	Image	FOMO MobileNetV2 0.35	56.8%	8.5%	51.3%	-	3 ms.	1.1M	112.7K	622 ms.
rgb-organization-6493-120	640×640	Image	YOLO-Pro	70.6%	50.0%	62.7%	-	×	-	-	29361 ms.
Impulse #17	96×96	Image	FOMO MobileNetV2 0.35	54.3%	3.3%	51.6%	-	3 ms.	435.2K	112.7K	225 ms.
model 3	96×96	Image	FOMO MobileNetV2 0.1	49.0%	8.9%	44.3%	-	3 ms.	399.7K	76.8K	212 ms.
model 4 (run3)	320×320	Image	YOLO-Pro	65.9%	34.4%	55.7%	-	3 ms.	399.7K	2.3M	8065 ms.
Model 5 (YOLO 96)	96×96	Image	YOLO-Pro	28.2%	44.4%	26.9%	-	3 ms.	836.3K	27.4M	6108 ms.
Impulse model 6	160×160	Image	FOMO MobileNetV2 0.35	52.8%	5.6%	50.3%	-	3 ms.	1.1M	112.7K	621 ms.

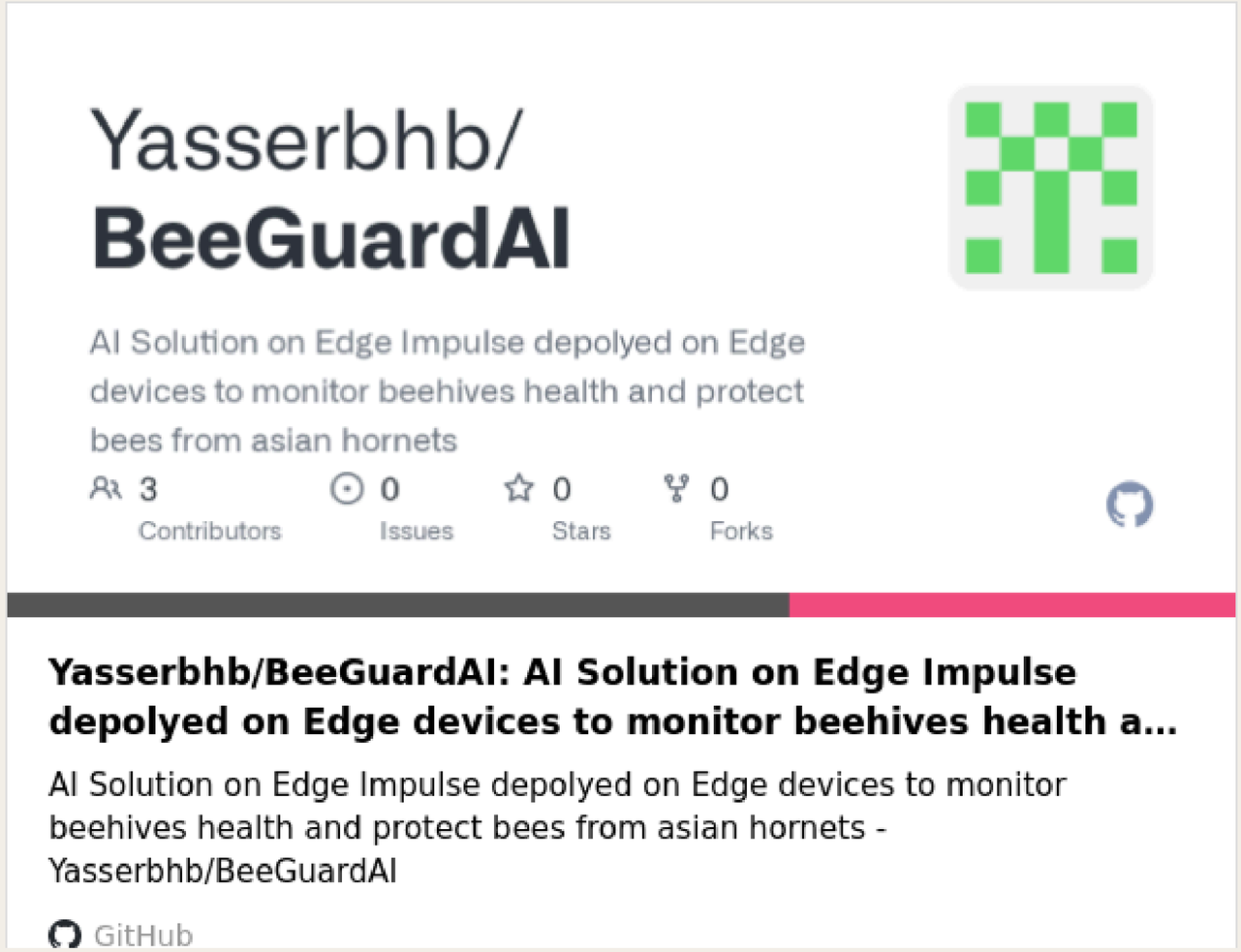
FOMO Model



FOMO (Faster Objects, More Objects) model configuration and results:

- F1-Score: 50.3%
- Confusion matrix showing classification of 3 classes (background, bees, hornet)
- Optimal on-device performance: 618ms inference, 321.1K peak RAM, 81.4K flash
- Much better suited for embedded systems than YOLO-Pro

Attachments



THANKS