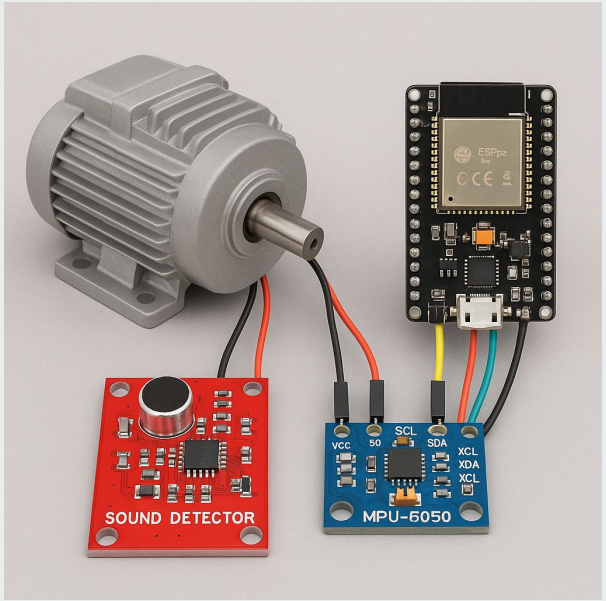
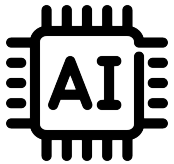


Detección de Anomalías en Motores usando TinyML en Edge

IoT 2025 - Trabajo Final
Mercado Bautista

Introducción - Elección del tema



- Fallas en motores -> Pérdidas significativas
- Difícil detectar ruidos o vibraciones anómalas a simple vista
- Solución compacta, local y de bajo costo
- Ideal para automatizar el análisis sin supervisión constante

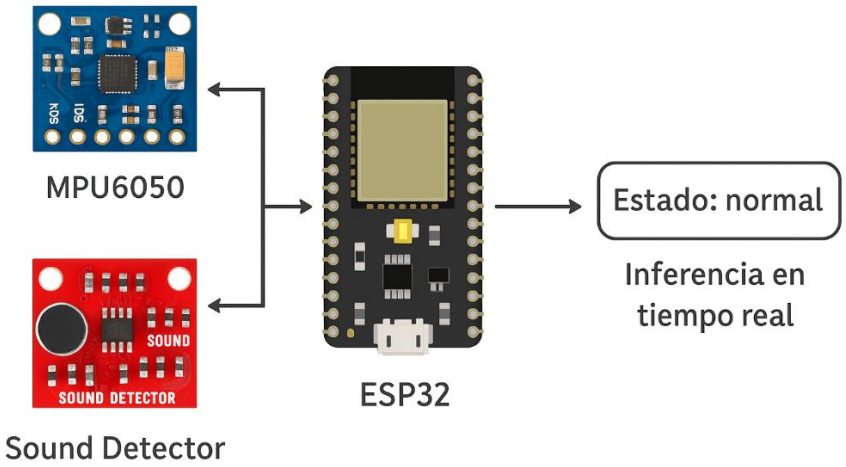
Problema: Detección de estados en motores sin monitoreo

- Muchos motores carecen de monitoreo
- No se distingue si están apagados, funcionando bien o con fallas
- No hay conexión a internet en todos los entornos
- Se necesita una solución simple, eficiente y local

Objetivo general y específicos del proyecto

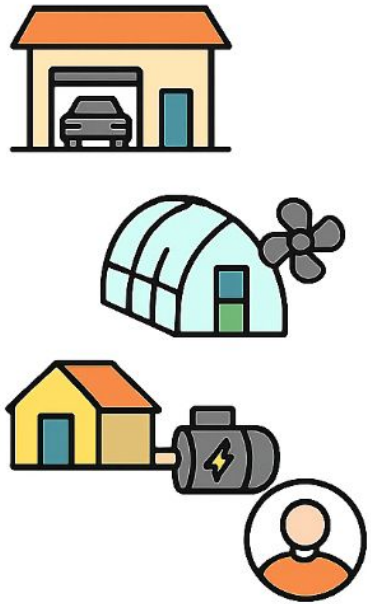
- Detectar el estado de un motor usando sensores y ML.
- Adquirir datos reales con ESP32, acelerómetro y micrófono.
- Entrenar un modelo con Edge Impulse.
- Implementar inferencias locales sin conexión a internet.
- Validar funcionamiento en un escenario real.

Solución aplicada



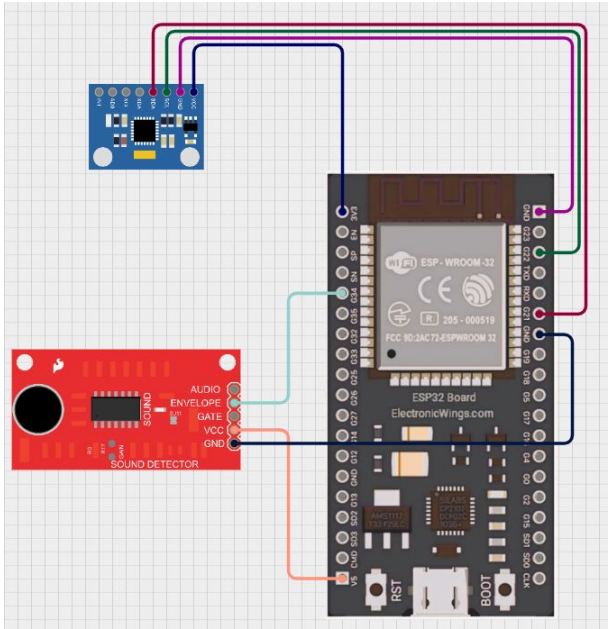
- Microcontrolador ESP32
- Sensores: MPU6050 (vibración) + Sound Detector (sonido)
- Modelo de clasificación entrenado con Edge Impulse
- Inferencia en tiempo real desde el ESP32

Aplicabilidad



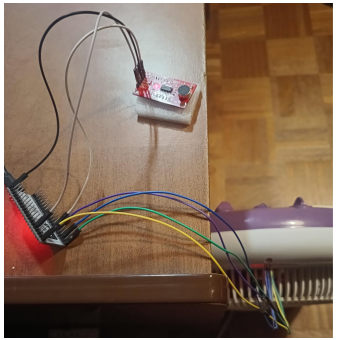
- Monitoreo de motores en talleres
- Extractores y ventiladores en invernaderos
- Sistemas autónomos sin red en zonas rurales
- Asistencia en inspecciones manuales.

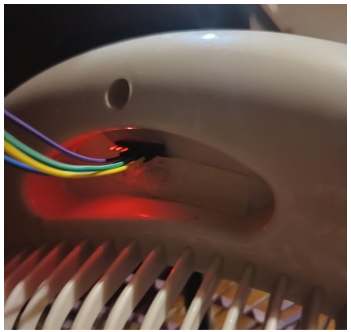
Arquitectura del Sistema



- ESP32 como microcontrolador.
- Sensores conectados por pines
  - MPU6050 (I2C digital)
    - VCC → 3.3V
    - GND → GND
    - SCL → GPIO22
    - SDA → GPIO21
  - Sound Detector (analógico)
    - VCC → 5V
    - GND → GND
    - ENVELOPE → GPIO34
- Modelo de Edge Impulse embebido
- Salida por monitor serie.

Puesta en marcha





- Verificación de sensores y comunicación correcta.
- Carga del sketch para recolección de muestras.
- Incorporación de sensores con ventilador.
- Entrenamiento del modelo en EI.
- Ejecución del modelo a través de un sketch de inferencias, mostrando los estados del motor.

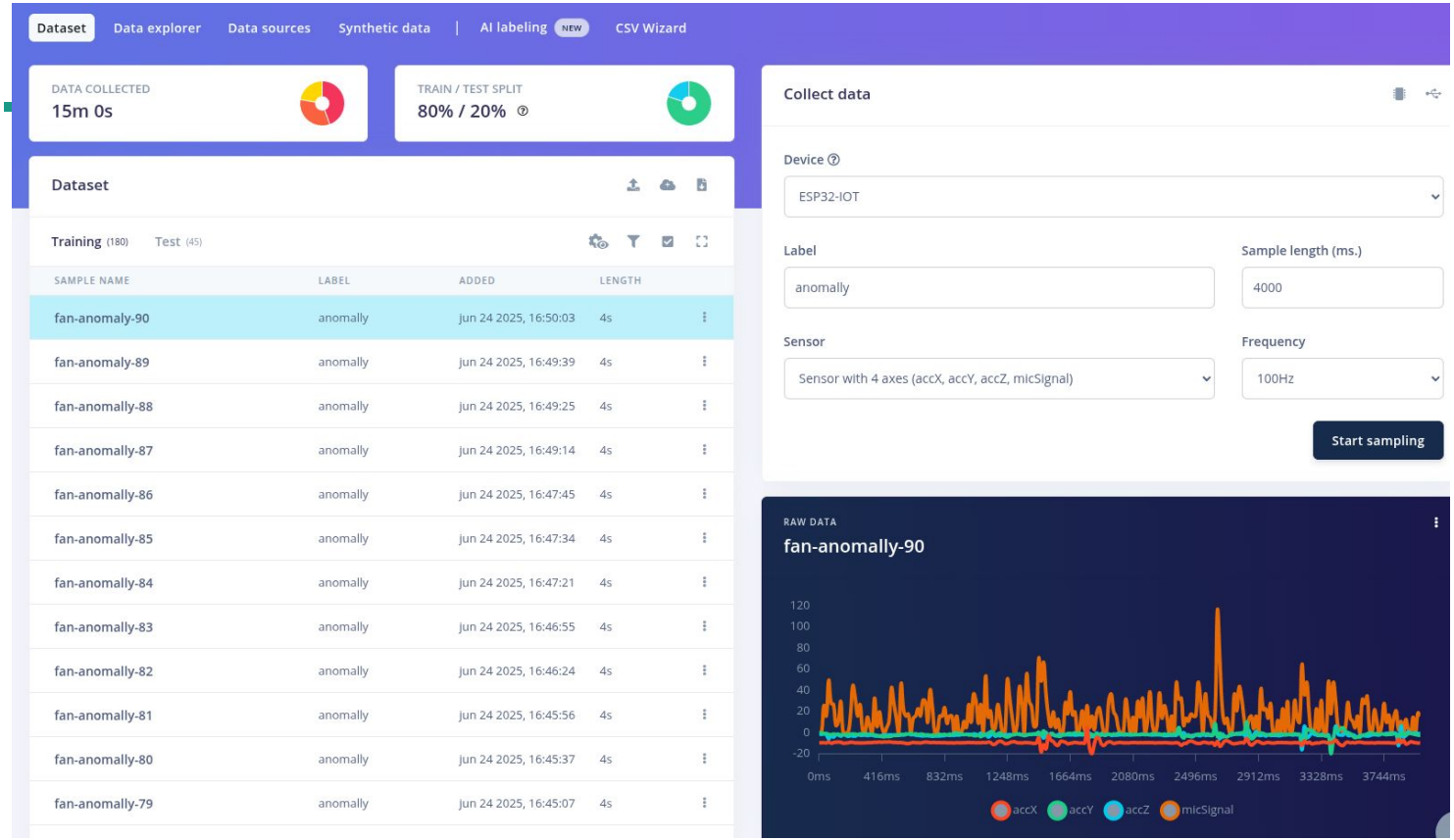
Recolección de Datos

```
20:06:41.546 -> -9.07,-1.46,-2.40,1
20:06:41.546 -> -9.10,-1.48,-2.38,0
20:06:41.578 -> -9.09,-1.49,-2.38,9
20:06:41.578 -> -9.08,-1.47,-2.37,5
20:06:41.578 -> -9.06,-1.46,-2.35,8
```

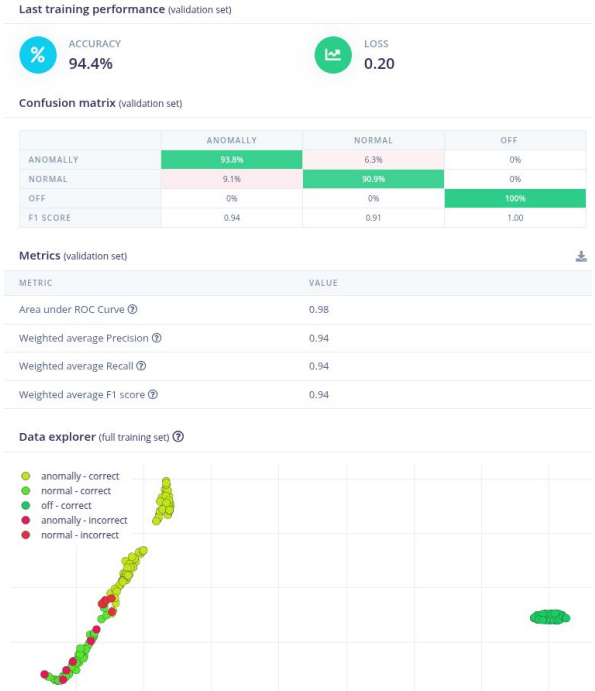
```
✘ bautista@bondiola ~ edge-impulse-data-forwarder
Edge Impulse data forwarder v1.32.1
WARN: You're running an outdated version of the Edge Impulse CLI tools
      Upgrade via `npm update -g edge-impulse-cli`
Endpoints:
    Websocket: wss://remote-mgmt.edgeimpulse.com
    API:       https://studio.edgeimpulse.com
    Ingestion: https://ingestion.edgeimpulse.com

[SER] Connecting to /dev/ttyUSB0
[SER] Failed to connect to /dev/ttyUSB0 retrying in 5 seconds Error: Device or resource busy, c
annot open /dev/ttyUSB0
[SER] You might need `sudo` or set up the right udev rules
[SER] Failed to connect to /dev/ttyUSB0 retrying in 5 seconds Error: Device or resource busy, c
annot open /dev/ttyUSB0
[SER] You might need `sudo` or set up the right udev rules
[SER] Serial is connected (00:01)
[WS ] Connecting to wss://remote-mgmt.edgeimpulse.com
[WS ] Connected to wss://remote-mgmt.edgeimpulse.com
[SER] Detecting data frequency...
[SER] Detected data frequency: 100Hz
[WS ] Device "ESP32-IOT" is now connected to project "iot2025-trabajofinal-ventilador". To conn
ect to another project, run `edge-impulse-data-forwarder --clean`.
[WS ] Go to https://studio.edgeimpulse.com/studio/727889/acquisition/training to build your mac
hine learning model!
```

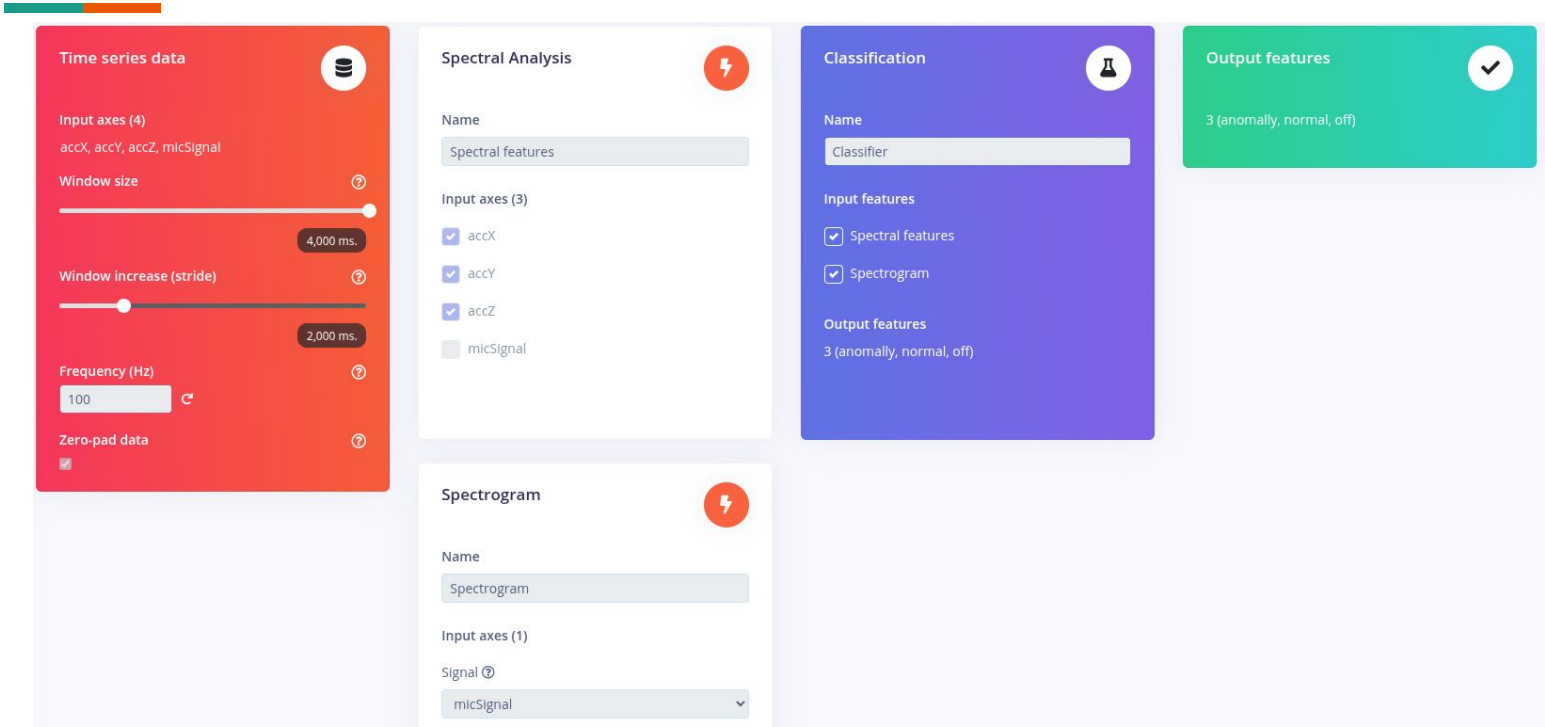
- Sketch que imprime accX,accY,accZ,micSignal a 100Hz.
- Uso de edge-impulse-data-forwarder para enviar los datos a EI.
- Captura de muestras de 4 segundos desde la web de Edge Impulse.
- Total: 225 muestras (180 training + 45 testing).


Dataset
Data explorer
Data sources
Synthetic data
AI labeling
NEW
CSV Wizard
DATA COLLECTED
15m 0s
TRAIN / TEST SPLIT
80% / 20%
Dataset
Training (180)
Test (45)
SAMPLE NAME
LABEL
ADDED
LENGTH
fan-anomaly-90 anomally jun 24 2025, 16:50:03 4s
fan-anomaly-89 anomally jun 24 2025, 16:49:39 4s
fan-anomally-88 anomally jun 24 2025, 16:49:25 4s
fan-anomally-87 anomally jun 24 2025, 16:49:14 4s
fan-anomally-86 anomally jun 24 2025, 16:47:45 4s
fan-anomally-85 anomally jun 24 2025, 16:47:34 4s
fan-anomally-84 anomally jun 24 2025, 16:47:21 4s
fan-anomally-83 anomally jun 24 2025, 16:46:55 4s
fan-anomally-82 anomally jun 24 2025, 16:46:24 4s
fan-anomally-81 anomally jun 24 2025, 16:45:56 4s
fan-anomally-80 anomally jun 24 2025, 16:45:37 4s
fan-anomally-79 anomally jun 24 2025, 16:45:07 4s
Collect data
Device
ESP32-IOT
Label
anomally
Sample length (ms.)
4000
Sensor
Sensor with 4 axes (accX, accY, accZ, micSignal)
Frequency
100Hz
Start sampling
RAW DATA
fan-anomally-90
120
100
80
60
40
20
0
-20
0ms
416ms
832ms
1248ms
1664ms
2080ms
2496ms
2912ms
3328ms
3744ms
accX
accY
accZ
micSignal

Entrenamiento del modelo



- Clasificación con ventanas de 4 segundos a 100Hz.
- Bloques de Procesamiento:
  - accX,accY,accZ → Spectral Analysis
  - micSignal → Spectrogram
- Bloque de aprendizaje → Classification
- Red neuronal con 3 capas densas (32 → 16 → 8)
- Accuracy 94.4%
- Modelo exportado → Quantized (int8)


Time series data
Input axes (4)
accX, accY, accZ, micSignal
Window size
4,000 ms.
Window increase (stride)
2,000 ms.
Frequency (Hz)
100
Zero-pad data
Spectral Analysis
Name
Spectral features
Input axes (3)
accX
accY
accZ
micSignal
Spectrogram
Name
Spectrogram
Input axes (1)
Signal
micSignal
Classification
Name
Classifier
Input features
Spectral features
Spectrogram
Output features
3 (anomally, normal, off)
Output features
3 (anomally, normal, off)

Training settings

Number of training cycles: 50

Use learned optimizer: ☐

Learning rate: 0.005

Training processor: CPU

Advanced training settings

Validation set size: 20

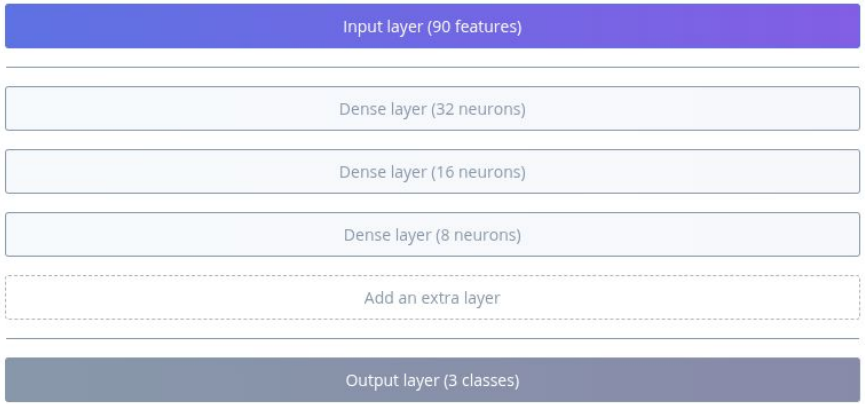
Split train/validation set on metadata key:

Batch size: 32

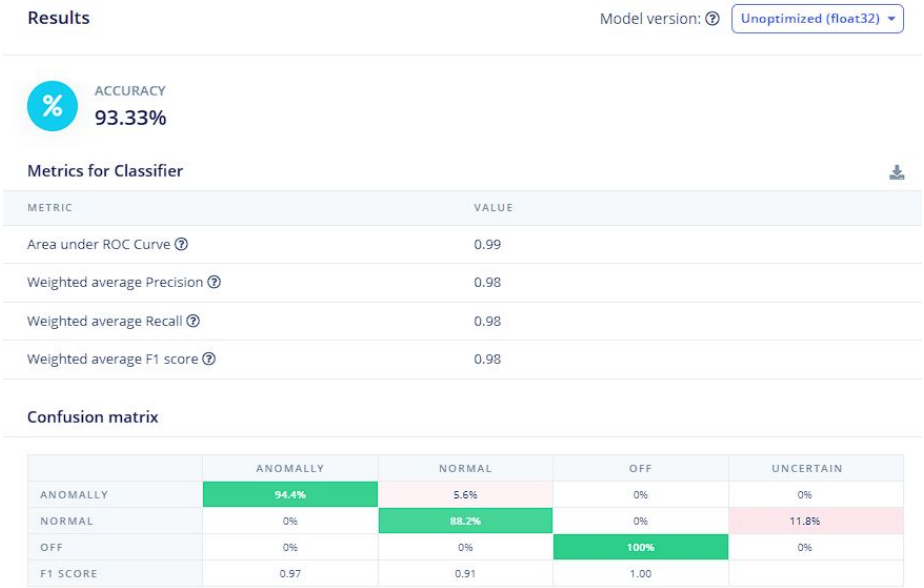
Auto-weight classes: ☑

Profile int8 model: ☑

Neural network architecture



Pruebas y Resultados



Results

Model version: Unoptimized (float32)

ACCURACY
93.33%

Metrics for Classifier

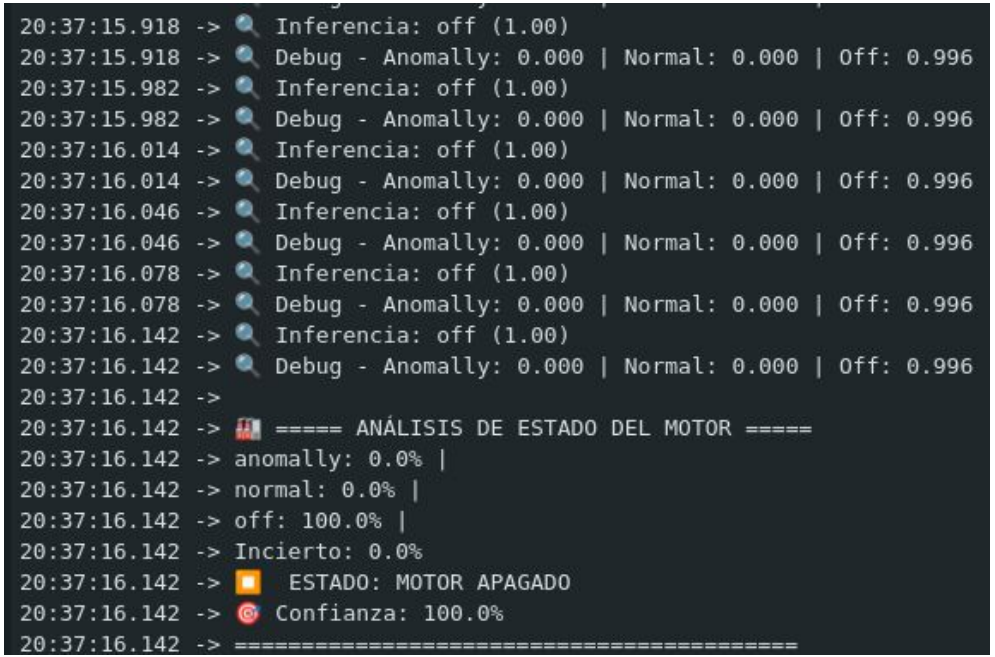
METRIC	VALUE
Area under ROC Curve	0.99
Weighted average Precision	0.98
Weighted average Recall	0.98
Weighted average F1 score	0.98

Confusion matrix

	ANOMALLY	NORMAL	OFF	UNCERTAIN
ANOMALLY	94.4%	5.6%	0%	0%
NORMAL	0%	88.2%	0%	11.8%
OFF	0%	0%	100%	0%
F1 SCORE	0.97	0.91	1.00	

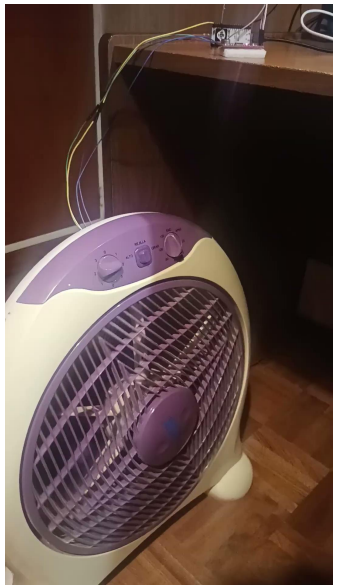
- Validación con 45 muestras para testing (20% del total).
- Precisión global: 93.33%
- Reconocimiento perfecto del estado OFF.
- Leve confusión entre NORMAL y ANOMALY.
- En pruebas reales, la clasificación es correcta para los estados usando ventilador.

Sketch Inferencias - OFF



- Recolección de muestras a 100Hz.
- El modelo se ejecuta cuando el buffer se llena (se agregan cada 4 seg).
- Umbral de confianza del 60%.
- Cada 5 segundos se muestra toma el estado más frecuente (con su nivel de confianza)

Inferencias - NORMAL



```
20:53:34.048 -> 🔍 Inferencia: normal (0.98)
20:53:34.048 -> 🔍 Debug - Anomally: 0.020 | Normal: 0.980 | Off: 0.000
20:53:34.080 -> 🔍 Inferencia: normal (0.98)
20:53:34.080 -> 🔍 Debug - Anomally: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.112 -> 🔍 Inferencia: normal (0.98)
20:53:34.112 -> 🔍 Debug - Anomally: 0.020 | Normal: 0.980 | Off: 0.000
20:53:34.176 -> 🔍 Inferencia: normal (0.98)
20:53:34.176 -> 🔍 Debug - Anomally: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.208 -> 🔍 Inferencia: normal (0.98)
20:53:34.208 -> 🔍 Debug - Anomally: 0.020 | Normal: 0.980 | Off: 0.000
20:53:34.240 -> 🔍 Inferencia: normal (0.98)
20:53:34.240 -> 🔍 Debug - Anomally: 0.016 | Normal: 0.984 | Off: 0.000
20:53:34.272 -> 🔍 Inferencia: normal (0.98)
20:53:34.272 -> 🔍 Debug - Anomally: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.336 -> 🔍 Inferencia: normal (0.98)
20:53:34.336 -> 🔍 Debug - Anomally: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.368 -> 🔍 Inferencia: normal (0.98)
20:53:34.368 -> 🔍 Debug - Anomally: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.400 -> 🔍 Inferencia: normal (0.98)
20:53:34.400 -> 🔍 Debug - Anomally: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.432 -> 🔍 Inferencia: normal (0.98)
20:53:34.432 -> 🔍 Debug - Anomally: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.464 -> 🔍 Inferencia: normal (0.98)
20:53:34.496 -> 🔍 Debug - Anomally: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.528 -> 🔍 Inferencia: normal (0.98)
20:53:34.528 -> 🔍 Debug - Anomally: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.560 -> 🔍 Inferencia: normal (0.98)
20:53:34.560 -> 🔍 Debug - Anomally: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.592 -> 🔍 Inferencia: normal (0.97)
20:53:34.592 -> 🔍 Debug - Anomally: 0.027 | Normal: 0.973 | Off: 0.000
20:53:34.592 ->
20:53:34.592 -> 🏭 ===== ANÁLISIS DE ESTADO DEL MOTOR =====
20:53:34.624 -> anomally: 0.0% |
20:53:34.624 -> normal: 100.0% |
20:53:34.624 -> off: 0.0% |
20:53:34.624 -> Incierto: 0.0%
20:53:34.624 -> ✅ ESTADO: FUNCIONAMIENTO NORMAL
20:53:34.624 -> 🎯 Confianza: 100.0%
20:53:34.624 -> ======================================
```

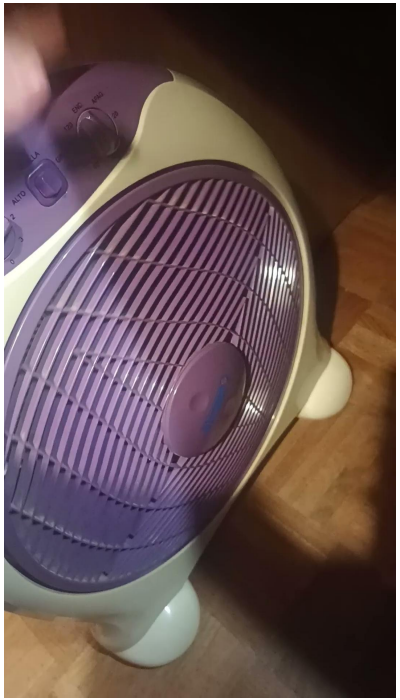
Inferencias - Cambio de base

```
21:14:37.805 -> 🔍 Inferencia: anomally (0.87)
21:14:37.837 -> 🔍 Debug - Anomally: 0.871 | Normal: 0.117 | Off: 0.012
21:14:37.868 -> 🔍 Inferencia: anomally (0.91)
21:14:37.868 -> 🔍 Debug - Anomally: 0.910 | Normal: 0.082 | Off: 0.008
21:14:37.900 -> 🔍 Inferencia: anomally (0.94)
21:14:37.900 -> 🔍 Debug - Anomally: 0.937 | Normal: 0.059 | Off: 0.004
21:14:37.933 -> 🔍 Inferencia: anomally (0.89)
21:14:37.933 -> 🔍 Debug - Anomally: 0.887 | Normal: 0.105 | Off: 0.008
21:14:37.965 -> 🔍 Inferencia: anomally (0.91)
21:14:37.965 -> 🔍 Debug - Anomally: 0.910 | Normal: 0.082 | Off: 0.008
21:14:38.030 -> 🔍 Inferencia: anomally (0.86)
21:14:38.030 -> 🔍 Debug - Anomally: 0.855 | Normal: 0.133 | Off: 0.012
21:14:38.064 -> 🔍 Inferencia: anomally (0.82)
21:14:38.064 -> 🔍 Debug - Anomally: 0.816 | Normal: 0.164 | Off: 0.016
21:14:38.095 -> 🔍 Inferencia: anomally (0.90)
21:14:38.095 -> 🔍 Debug - Anomally: 0.898 | Normal: 0.094 | Off: 0.008
21:14:38.127 -> 🔍 Inferencia: anomally (0.87)
21:14:38.127 -> 🔍 Debug - Anomally: 0.871 | Normal: 0.117 | Off: 0.012
21:14:38.159 -> 🔍 Inferencia: anomally (0.82)
21:14:38.192 -> 🔍 Debug - Anomally: 0.816 | Normal: 0.164 | Off: 0.016
21:14:38.225 -> 🔍 Inferencia: anomally (0.87)
21:14:38.225 -> 🔍 Debug - Anomally: 0.871 | Normal: 0.117 | Off: 0.012
21:14:38.258 -> 🔍 Inferencia: anomally (0.94)
21:14:38.258 -> 🔍 Debug - Anomally: 0.937 | Normal: 0.059 | Off: 0.008
21:14:38.291 -> 🔍 Inferencia: anomally (0.91)
21:14:38.291 -> 🔍 Debug - Anomally: 0.914 | Normal: 0.074 | Off: 0.012
21:14:38.323 -> 🔍 Inferencia: anomally (0.92)
21:14:38.323 -> 🔍 Debug - Anomally: 0.918 | Normal: 0.074 | Off: 0.008
21:14:38.356 -> 🔍 Inferencia: anomally (0.95)
21:14:38.387 -> 🔍 Debug - Anomally: 0.949 | Normal: 0.043 | Off: 0.004
21:14:38.387 ->
21:14:38.387 -> 🏭 ===== ANÁLISIS DE ESTADO DEL MOTOR =====
21:14:38.387 -> anomally: 100.0% |
21:14:38.387 -> normal: 0.0% |
21:14:38.387 -> off: 0.0% |
21:14:38.387 -> Incierto: 0.0%
21:14:38.387 -> 🚨 ESTADO: ANOMALÍA DETECTADA - Revisar motor inmediatamente!
21:14:38.387 -> ⚠  Posibles causas: desbalanceo, desgaste, falla mecánica, etc.
```

Inferencias - Desbalanceo

```
21:00:48.614 -> 🔍 Inferencia: anomally (0.82)
21:00:48.614 -> 🔍 Debug - Anomally: 0.816 | Normal: 0.164 | Off: 0.016
21:00:48.647 -> 🔍 Inferencia: anomally (0.80)
21:00:48.647 -> 🔍 Debug - Anomally: 0.797 | Normal: 0.184 | Off: 0.020
21:00:48.679 -> 🔍 Inferencia: anomally (0.78)
21:00:48.679 -> 🔍 Debug - Anomally: 0.777 | Normal: 0.203 | Off: 0.020
21:00:48.711 -> 🔍 Inferencia: anomally (0.76)
21:00:48.711 -> 🔍 Debug - Anomally: 0.758 | Normal: 0.227 | Off: 0.016
21:00:48.775 -> 🔍 Inferencia: anomally (0.76)
21:00:48.775 -> 🔍 Debug - Anomally: 0.758 | Normal: 0.227 | Off: 0.016
21:00:48.807 -> 🔍 Inferencia: anomally (0.65)
21:00:48.807 -> 🔍 Debug - Anomally: 0.648 | Normal: 0.332 | Off: 0.020
21:00:48.839 -> 🔍 Inferencia: anomally (0.82)
21:00:48.839 -> 🔍 Debug - Anomally: 0.820 | Normal: 0.168 | Off: 0.012
21:00:48.871 -> 🔍 Inferencia: anomally (0.73)
21:00:48.871 -> 🔍 Debug - Anomally: 0.730 | Normal: 0.250 | Off: 0.020
21:00:48.903 -> 🔍 Inferencia: anomally (0.78)
21:00:48.935 -> 🔍 Debug - Anomally: 0.781 | Normal: 0.207 | Off: 0.016
21:00:48.967 -> 🔍 Inferencia: anomally (0.82)
21:00:48.967 -> 🔍 Debug - Anomally: 0.820 | Normal: 0.168 | Off: 0.012
21:00:48.999 -> 🔍 Inferencia: anomally (0.91)
21:00:48.999 -> 🔍 Debug - Anomally: 0.910 | Normal: 0.082 | Off: 0.004
21:00:49.031 -> 🔍 Inferencia: anomally (0.86)
21:00:49.031 -> 🔍 Debug - Anomally: 0.859 | Normal: 0.133 | Off: 0.008
21:00:49.063 -> 🔍 Inferencia: anomally (0.80)
21:00:49.063 -> 🔍 Debug - Anomally: 0.797 | Normal: 0.184 | Off: 0.016
21:00:49.127 -> 🔍 Inferencia: anomally (0.80)
21:00:49.127 -> 🔍 Debug - Anomally: 0.801 | Normal: 0.184 | Off: 0.016
21:00:49.127 ->
21:00:49.127 -> 🏭 ===== ANÁLISIS DE ESTADO DEL MOTOR =====
21:00:49.127 -> anomally: 100.0% |
21:00:49.127 -> normal: 0.0% |
21:00:49.127 -> off: 0.0% |
21:00:49.127 -> Incierto: 0.0%
21:00:49.127 -> 🚨 ESTADO: ANOMALÍA DETECTADA - Revisar motor inmediatamente!
21:00:49.127 -> ⚠️  Posibles causas: desbalanceo, desgaste, falla mecánica, etc.
21:00:49.159 -> 🎯 Confianza: 100.0%
21:00:49.159 -> ========================================
21:00:49.159 ->
21:00:49.191 -> 🔍 Inferencia: anomally (0.87)
```

Inferencias - Golpes



```
20:59:17.934 -> 🔍 Inferencia: anomally (0.96)
20:59:17.934 -> 🔍 Debug - Anomally: 0.965 | Normal: 0.031 | Off: 0.008
20:59:17.966 -> 🔍 Inferencia: anomally (0.97)
20:59:17.998 -> 🔍 Debug - Anomally: 0.969 | Normal: 0.027 | Off: 0.004
20:59:18.030 -> 🔍 Inferencia: anomally (0.96)
20:59:18.030 -> 🔍 Debug - Anomally: 0.961 | Normal: 0.031 | Off: 0.008
20:59:18.062 -> 🔍 Inferencia: anomally (0.96)
20:59:18.062 -> 🔍 Debug - Anomally: 0.957 | Normal: 0.035 | Off: 0.008
20:59:18.094 -> 🔍 Inferencia: anomally (0.96)
20:59:18.094 -> 🔍 Debug - Anomally: 0.965 | Normal: 0.027 | Off: 0.008
20:59:18.126 -> 🔍 Inferencia: anomally (0.96)
20:59:18.158 -> 🔍 Debug - Anomally: 0.961 | Normal: 0.031 | Off: 0.008
20:59:18.190 -> 🔍 Inferencia: anomally (0.96)
20:59:18.190 -> 🔍 Debug - Anomally: 0.961 | Normal: 0.031 | Off: 0.008
20:59:18.222 -> 🔍 Inferencia: anomally (0.96)
20:59:18.222 -> 🔍 Debug - Anomally: 0.961 | Normal: 0.031 | Off: 0.008
20:59:18.254 -> 🔍 Inferencia: anomally (0.97)
20:59:18.254 -> 🔍 Debug - Anomally: 0.973 | Normal: 0.023 | Off: 0.004
20:59:18.286 -> 🔍 Inferencia: anomally (1.00)
20:59:18.286 -> 🔍 Debug - Anomally: 0.996 | Normal: 0.004 | Off: 0.000
20:59:18.350 -> 🔍 Inferencia: anomally (0.99)
20:59:18.350 -> 🔍 Debug - Anomally: 0.992 | Normal: 0.008 | Off: 0.000
20:59:18.383 -> 🔍 Inferencia: anomally (0.98)
20:59:18.383 -> 🔍 Debug - Anomally: 0.984 | Normal: 0.016 | Off: 0.004
20:59:18.415 -> 🔍 Inferencia: anomally (0.99)
20:59:18.415 -> 🔍 Debug - Anomally: 0.992 | Normal: 0.008 | Off: 0.000
20:59:18.448 -> 🔍 Inferencia: anomally (0.99)
20:59:18.448 -> 🔍 Debug - Anomally: 0.992 | Normal: 0.004 | Off: 0.000
20:59:18.480 -> 🔍 Inferencia: anomally (0.99)
20:59:18.512 -> 🔍 Debug - Anomally: 0.992 | Normal: 0.008 | Off: 0.000
20:59:18.545 -> 🔍 Inferencia: anomally (0.99)
20:59:18.545 -> 🔍 Debug - Anomally: 0.992 | Normal: 0.008 | Off: 0.000
20:59:18.578 -> 🔍 Inferencia: anomally (0.99)
20:59:18.578 -> 🔍 Debug - Anomally: 0.988 | Normal: 0.008 | Off: 0.000
20:59:18.611 -> 🔍 Inferencia: anomally (0.99)
20:59:18.611 -> 🔍 Debug - Anomally: 0.992 | Normal: 0.008 | Off: 0.000
20:59:18.611 ->
20:59:18.611 -> 🏭 ===== ANÁLISIS DE ESTADO DEL MOTOR =====
20:59:18.611 -> anomally: 100.0% |
20:59:18.611 -> normal: 0.0% |
20:59:18.611 -> off: 0.0% |
20:59:18.644 -> Incierto: 0.0%
20:59:18.644 -> 🚨 ESTADO: ANOMALÍA DETECTADA - Revisar motor inmediatamente!
20:59:18.644 -> ⚠  Posibles causas: desbalanceo, desgaste, falla mecánica, etc.
```

Inferencias - Inclinación

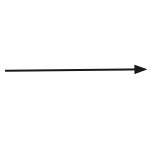
```
17:57:44.215 -> 🔍 Inferencia: anomally (0.75)
17:57:44.215 -> 🔍 Debug - Anomally: 0.754 | Normal: 0.227 | Off: 0.020
17:57:44.248 -> 🔍 Inferencia: anomally (0.84)
17:57:44.248 -> 🔍 Debug - Anomally: 0.840 | Normal: 0.148 | Off: 0.012
17:57:44.280 -> 🔍 Inferencia: anomally (0.64)
17:57:44.280 -> 🔍 Debug - Anomally: 0.637 | Normal: 0.328 | Off: 0.035
17:57:44.345 -> ❓ Inferencia incierta
17:57:44.377 -> ❓ Inferencia incierta
17:57:44.409 -> 🔍 Inferencia: anomally (0.64)
17:57:44.409 -> 🔍 Debug - Anomally: 0.637 | Normal: 0.328 | Off: 0.035
17:57:44.441 -> 🔍 Inferencia: anomally (0.60)
17:57:44.441 -> 🔍 Debug - Anomally: 0.602 | Normal: 0.352 | Off: 0.047
17:57:44.473 -> ❓ Inferencia incierta
17:57:44.540 -> 🔍 Inferencia: normal (0.60)
17:57:44.540 -> 🔍 Debug - Anomally: 0.352 | Normal: 0.602 | Off: 0.047
17:57:44.572 -> 🔍 Inferencia: normal (0.60)
17:57:44.572 -> 🔍 Debug - Anomally: 0.352 | Normal: 0.602 | Off: 0.047
17:57:44.605 -> ❓ Inferencia incierta
17:57:44.636 -> ❓ Inferencia incierta
17:57:44.669 -> 🔍 Inferencia: normal (0.61)
17:57:44.669 -> 🔍 Debug - Anomally: 0.355 | Normal: 0.605 | Off: 0.035
17:57:44.733 -> 🔍 Inferencia: normal (0.69)
17:57:44.733 -> 🔍 Debug - Anomally: 0.273 | Normal: 0.691 | Off: 0.035
17:57:44.767 -> 🔍 Inferencia: normal (0.74)
17:57:44.767 -> 🔍 Debug - Anomally: 0.223 | Normal: 0.738 | Off: 0.039
17:57:44.799 -> 🔍 Inferencia: normal (0.74)
17:57:44.799 -> 🔍 Debug - Anomally: 0.223 | Normal: 0.738 | Off: 0.039
17:57:44.832 -> 🔍 Inferencia: normal (0.74)
17:57:44.832 -> 🔍 Debug - Anomally: 0.223 | Normal: 0.738 | Off: 0.039
17:57:44.864 -> 🔍 Inferencia: normal (0.69)
17:57:44.896 -> 🔍 Debug - Anomally: 0.273 | Normal: 0.691 | Off: 0.035
17:57:44.929 -> 🔍 Inferencia: normal (0.74)
17:57:44.929 -> 🔍 Debug - Anomally: 0.223 | Normal: 0.738 | Off: 0.039
17:57:44.929 ->
17:57:44.929 -> 🏭 ===== ANÁLISIS DE ESTADO DEL MOTOR =====
17:57:44.929 -> anomaly: 86.3% |
17:57:44.929 -> normal: 8.8% |
17:57:44.929 -> off: 0.0% |
17:57:44.929 -> Incierto: 4.9%
17:57:44.929 -> 🚨 ESTADO: ANOMALÍA DETECTADA - Revisar motor inmediatamente!
17:57:44.929 -> ⚠  Posibles causas: desbalanceo, desgaste, falla mecánica, etc.
17:57:44.961 -> 🎯 Confianza: 86.3%
17:57:44.961 -> ============================================
```

Inferencias - Obstrucción

```
21:22:11.332 -> 🔍 Debug - Anomally: 0.871 | Normal: 0.117 | Off: 0.008
21:22:11.365 -> 🔍 Inferencia: anomally (0.86)
21:22:11.365 -> 🔍 Debug - Anomally: 0.855 | Normal: 0.133 | Off: 0.012
21:22:11.397 -> 🔍 Inferencia: anomally (0.86)
21:22:11.397 -> 🔍 Debug - Anomally: 0.855 | Normal: 0.133 | Off: 0.012
21:22:11.462 -> 🔍 Inferencia: anomally (0.86)
21:22:11.462 -> 🔍 Debug - Anomally: 0.855 | Normal: 0.133 | Off: 0.012
21:22:11.496 -> 🔍 Inferencia: anomally (0.95)
21:22:11.496 -> 🔍 Debug - Anomally: 0.945 | Normal: 0.051 | Off: 0.004
21:22:11.529 -> 🔍 Inferencia: anomally (0.90)
21:22:11.529 -> 🔍 Debug - Anomally: 0.898 | Normal: 0.094 | Off: 0.008
21:22:11.561 -> 🔍 Inferencia: anomally (0.91)
21:22:11.561 -> 🔍 Debug - Anomally: 0.910 | Normal: 0.082 | Off: 0.008
21:22:11.594 -> 🔍 Inferencia: anomally (0.91)
21:22:11.594 -> 🔍 Debug - Anomally: 0.910 | Normal: 0.082 | Off: 0.008
21:22:11.659 -> 🔍 Inferencia: anomally (0.89)
21:22:11.659 -> 🔍 Debug - Anomally: 0.887 | Normal: 0.105 | Off: 0.008
21:22:11.692 -> 🔍 Inferencia: anomally (0.90)
21:22:11.692 -> 🔍 Debug - Anomally: 0.902 | Normal: 0.094 | Off: 0.004
21:22:11.725 -> 🔍 Inferencia: anomally (0.84)
21:22:11.725 -> 🔍 Debug - Anomally: 0.844 | Normal: 0.148 | Off: 0.008
21:22:11.759 -> 🔍 Inferencia: anomally (0.88)
21:22:11.759 -> 🔍 Debug - Anomally: 0.875 | Normal: 0.117 | Off: 0.008
21:22:11.790 -> 🔍 Inferencia: anomally (0.86)
21:22:11.823 -> 🔍 Debug - Anomally: 0.855 | Normal: 0.133 | Off: 0.012
21:22:11.856 -> 🔍 Inferencia: anomally (0.90)
21:22:11.856 -> 🔍 Debug - Anomally: 0.902 | Normal: 0.094 | Off: 0.004
21:22:11.856 ->
21:22:11.856 -> 🏭 ===== ANÁLISIS DE ESTADO DEL MOTOR =====
21:22:11.856 -> anomally: 100.0% |
21:22:11.856 -> normal: 0.0% |
21:22:11.856 -> off: 0.0% |
21:22:11.856 -> Incierto: 0.0%
21:22:11.856 -> 🚨 ESTADO: ANOMALÍA DETECTADA - Revisar motor inmediatamente!
21:22:11.856 -> ⚠ Posibles causas: desbalanceo, desgaste, falla mecánica, etc.
21:22:11.888 -> 🎯 Confianza: 100.0%
21:22:11.888 -> ========================================
21:22:11.888 ->
```

Problemas y Soluciones

El cooler no generaba suficientes vibraciones ni ruido



Se cambió a un ventilador, con señales más claras

El modelo confundía NORMAL y ANOMALY

Se recolectaron más muestras y con mayor diversidad de fallos

Dataset inicial muy chico (120 muestras de entrenamiento)

Se amplió a 180 muestras para entrenamiento

Conclusiones

Buen rendimiento final del modelo

Importancia de la iteración y la experimentación

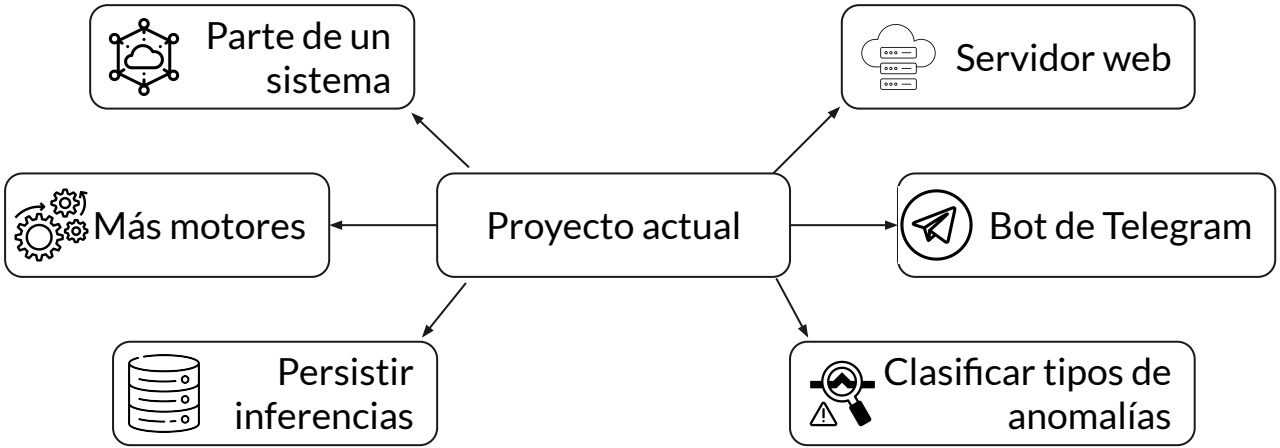
Dataset amplio, balanceado y variado es clave

Elección de sensores dependerá del motor

Ideal para contextos sin conectividad y bajo costo

El facilita el ciclo completo de desarrollo de TinyML

Trabajos Futuros



¡Gracias!

¿Consultas?

Repositorio del proyecto en GitHub

CREDITS: This presentation includes icons by Flaticon and images by DALLE-3