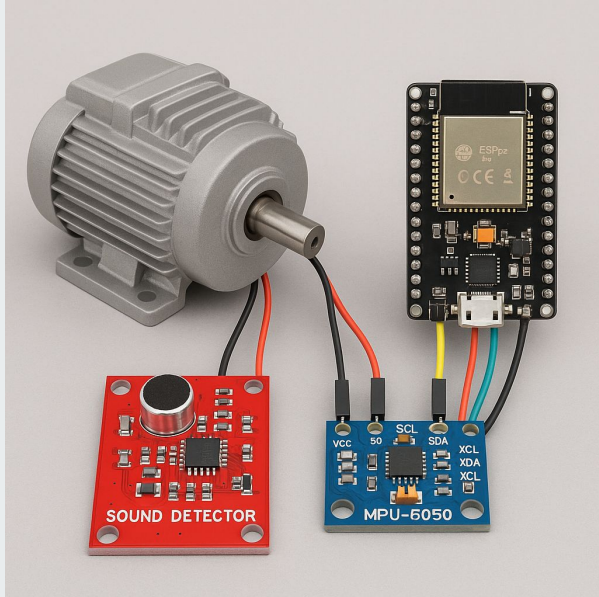


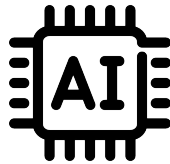
Detección de Anomalías en Motores usando TinyML en Edge

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 entornos 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



Sensado



Recolección
de datos



Entrenamiento



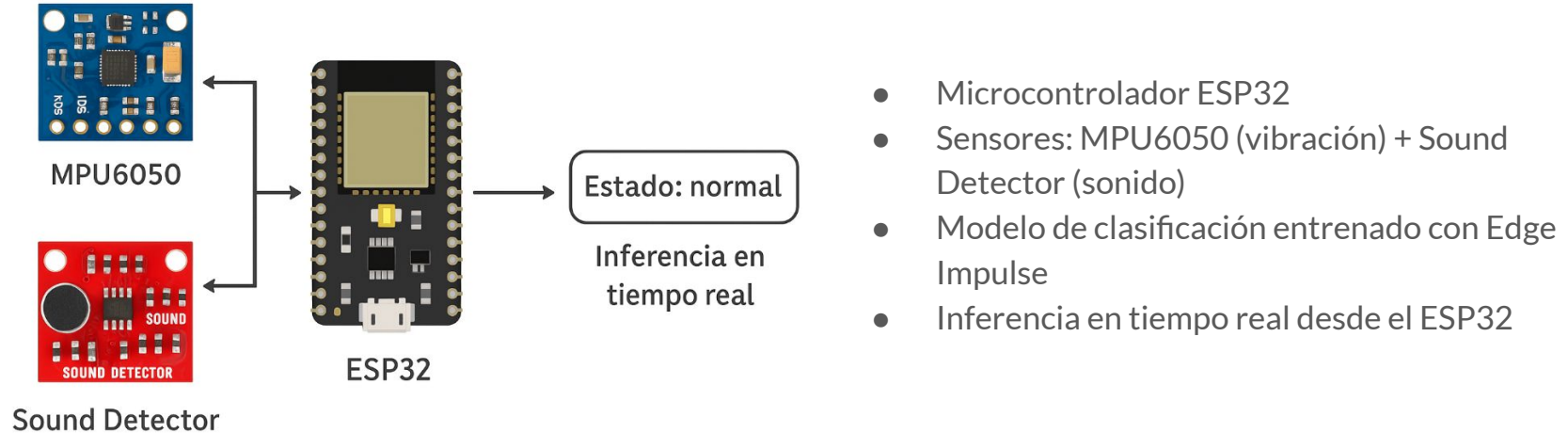
Inferencia



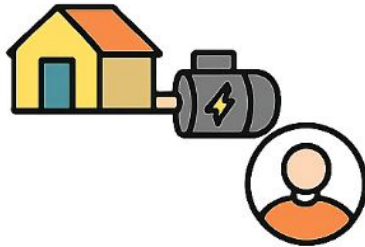
Validación

- 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

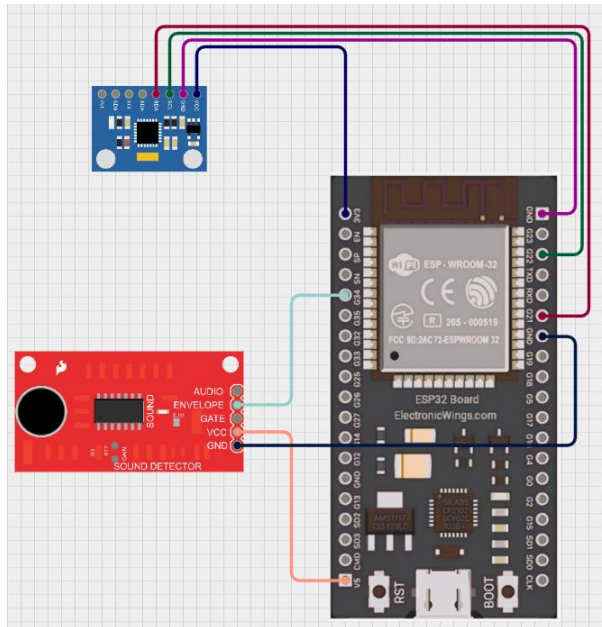


Aplicabilidad



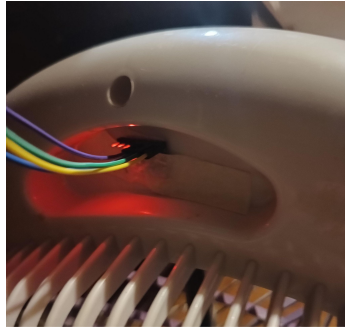
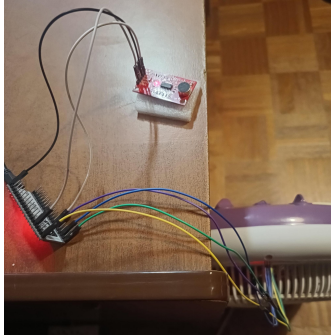
- Monitoreo de motores en talleres
- Extractores y ventiladores en invernaderos
- Sistemas autónomos sin red en zonas rurales
- Asistencia en inspecciones manuales.

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	anomaly	jun 24 2025, 16:50:03	4s
fan-anomaly-89	anomaly	jun 24 2025, 16:49:39	4s
fan-anomaly-88	anomaly	jun 24 2025, 16:49:25	4s
fan-anomaly-87	anomaly	jun 24 2025, 16:49:14	4s
fan-anomaly-86	anomaly	jun 24 2025, 16:47:45	4s
fan-anomaly-85	anomaly	jun 24 2025, 16:47:34	4s
fan-anomaly-84	anomaly	jun 24 2025, 16:47:21	4s
fan-anomaly-83	anomaly	jun 24 2025, 16:46:55	4s
fan-anomaly-82	anomaly	jun 24 2025, 16:46:24	4s
fan-anomaly-81	anomaly	jun 24 2025, 16:45:56	4s
fan-anomaly-80	anomaly	jun 24 2025, 16:45:37	4s
fan-anomaly-79	anomaly	jun 24 2025, 16:45:07	4s

Collect data



Device ?

ESP32-IOT

Label

anomaly

Sample length (ms.)

4000

Sensor

Sensor with 4 axes (accX, accY, accZ, micSignal)

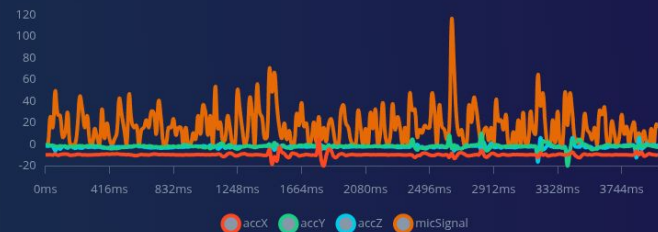
Frequency

100Hz

Start sampling

RAW DATA

fan-anomaly-90



Entrenamiento del modelo

Last training performance (validation set)



ACCURACY
94.4%



LOSS
0.20

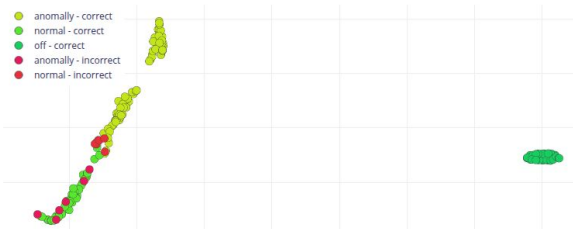
Confusion matrix (validation set)

	ANOMALLY	NORMAL	OFF
ANOMALLY	93.8%	6.3%	0%
NORMAL	9.1%	90.9%	0%
OFF	0%	0%	100%
F1 SCORE	0.94	0.91	1.00

Metrics (validation set)

METRIC	VALUE
Area under ROC Curve [Ⓢ]	0.98
Weighted average Precision [Ⓢ]	0.94
Weighted average Recall [Ⓢ]	0.94
Weighted average F1 score [Ⓢ]	0.94

Data explorer (full training set) [Ⓢ]



- Clasificación con ventanas de 4 segundos a 100Hz.
- Procesamiento
 - accX, accY, accZ → Spectral Analysis
 - micSignal → Spectrogram
- 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 (anomaly, normal, off)

Output features



3 (anomaly, normal, off)

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

```
20:37:15.918 -> 🔍 Inferencia: off (1.00)
20:37:15.918 -> 🔍 Debug - Anomaly: 0.000 | Normal: 0.000 | Off: 0.996
20:37:15.982 -> 🔍 Inferencia: off (1.00)
20:37:15.982 -> 🔍 Debug - Anomaly: 0.000 | Normal: 0.000 | Off: 0.996
20:37:16.014 -> 🔍 Inferencia: off (1.00)
20:37:16.014 -> 🔍 Debug - Anomaly: 0.000 | Normal: 0.000 | Off: 0.996
20:37:16.046 -> 🔍 Inferencia: off (1.00)
20:37:16.046 -> 🔍 Debug - Anomaly: 0.000 | Normal: 0.000 | Off: 0.996
20:37:16.078 -> 🔍 Inferencia: off (1.00)
20:37:16.078 -> 🔍 Debug - Anomaly: 0.000 | Normal: 0.000 | Off: 0.996
20:37:16.142 -> 🔍 Inferencia: off (1.00)
20:37:16.142 -> 🔍 Debug - Anomaly: 0.000 | Normal: 0.000 | Off: 0.996
20:37:16.142 -> 🚨 ===== ANÁLISIS DE ESTADO DEL MOTOR =====
20:37:16.142 -> anomaly: 0.0% |
20:37:16.142 -> normal: 0.0% |
20:37:16.142 -> off: 100.0% |
20:37:16.142 -> Incierto: 0.0%
20:37:16.142 -> 🛑 ESTADO: MOTOR APAGADO
20:37:16.142 -> 📊 Confianza: 100.0%
20:37:16.142 -> =====
```

- 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 - Anomaly: 0.020 | Normal: 0.980 | Off: 0.000
20:53:34.080 -> Inferencia: normal (0.98)
20:53:34.080 -> Debug - Anomaly: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.112 -> Inferencia: normal (0.98)
20:53:34.112 -> Debug - Anomaly: 0.020 | Normal: 0.980 | Off: 0.000
20:53:34.176 -> Inferencia: normal (0.98)
20:53:34.176 -> Debug - Anomaly: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.208 -> Inferencia: normal (0.98)
20:53:34.208 -> Debug - Anomaly: 0.020 | Normal: 0.980 | Off: 0.000
20:53:34.240 -> Inferencia: normal (0.98)
20:53:34.240 -> Debug - Anomaly: 0.016 | Normal: 0.984 | Off: 0.000
20:53:34.272 -> Inferencia: normal (0.98)
20:53:34.272 -> Debug - Anomaly: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.336 -> Inferencia: normal (0.98)
20:53:34.336 -> Debug - Anomaly: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.368 -> Inferencia: normal (0.98)
20:53:34.368 -> Debug - Anomaly: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.400 -> Inferencia: normal (0.98)
20:53:34.400 -> Debug - Anomaly: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.432 -> Inferencia: normal (0.98)
20:53:34.432 -> Debug - Anomaly: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.464 -> Inferencia: normal (0.98)
20:53:34.496 -> Debug - Anomaly: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.528 -> Inferencia: normal (0.98)
20:53:34.528 -> Debug - Anomaly: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.560 -> Inferencia: normal (0.98)
20:53:34.560 -> Debug - Anomaly: 0.023 | Normal: 0.977 | Off: 0.000
20:53:34.592 -> Inferencia: normal (0.97)
20:53:34.592 -> Debug - Anomaly: 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 -> anomaly: 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: anomaly (0.87)
21:14:37.837 -> Debug - Anomaly: 0.871 | Normal: 0.117 | Off: 0.012
21:14:37.868 -> Inferencia: anomaly (0.91)
21:14:37.868 -> Debug - Anomaly: 0.910 | Normal: 0.082 | Off: 0.008
21:14:37.900 -> Inferencia: anomaly (0.94)
21:14:37.900 -> Debug - Anomaly: 0.937 | Normal: 0.059 | Off: 0.004
21:14:37.933 -> Inferencia: anomaly (0.89)
21:14:37.933 -> Debug - Anomaly: 0.887 | Normal: 0.105 | Off: 0.008
21:14:37.965 -> Inferencia: anomaly (0.91)
21:14:37.965 -> Debug - Anomaly: 0.910 | Normal: 0.082 | Off: 0.008
21:14:38.030 -> Inferencia: anomaly (0.86)
21:14:38.030 -> Debug - Anomaly: 0.855 | Normal: 0.133 | Off: 0.012
21:14:38.064 -> Inferencia: anomaly (0.82)
21:14:38.064 -> Debug - Anomaly: 0.816 | Normal: 0.164 | Off: 0.016
21:14:38.095 -> Inferencia: anomaly (0.90)
21:14:38.095 -> Debug - Anomaly: 0.898 | Normal: 0.094 | Off: 0.008
21:14:38.127 -> Inferencia: anomaly (0.87)
21:14:38.127 -> Debug - Anomaly: 0.871 | Normal: 0.117 | Off: 0.012
21:14:38.159 -> Inferencia: anomaly (0.82)
21:14:38.192 -> Debug - Anomaly: 0.816 | Normal: 0.164 | Off: 0.016
21:14:38.225 -> Inferencia: anomaly (0.87)
21:14:38.225 -> Debug - Anomaly: 0.871 | Normal: 0.117 | Off: 0.012
21:14:38.258 -> Inferencia: anomaly (0.94)
21:14:38.258 -> Debug - Anomaly: 0.937 | Normal: 0.059 | Off: 0.008
21:14:38.291 -> Inferencia: anomaly (0.91)
21:14:38.291 -> Debug - Anomaly: 0.914 | Normal: 0.074 | Off: 0.012
21:14:38.323 -> Inferencia: anomaly (0.92)
21:14:38.323 -> Debug - Anomaly: 0.918 | Normal: 0.074 | Off: 0.008
21:14:38.356 -> Inferencia: anomaly (0.95)
21:14:38.387 -> Debug - Anomaly: 0.949 | Normal: 0.043 | Off: 0.004
21:14:38.387 ->
21:14:38.387 -> ===== ANALISIS DE ESTADO DEL MOTOR =====
21:14:38.387 -> anomaly: 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: ANOMALIA DETECTADA - Revisar motor inmediatamente!
21:14:38.387 -> Posibles causas: desbalanceo, desgaste, falla mecánica, etc.
21:14:38.387 -> Confianza: 100.0%
```


Inferencias - Desbalanceo



```
21:00:48.614 -> Inferencia: anomaly (0.82)
21:00:48.614 -> Debug - Anomaly: 0.816 | Normal: 0.164 | Off: 0.016
21:00:48.647 -> Inferencia: anomaly (0.80)
21:00:48.647 -> Debug - Anomaly: 0.797 | Normal: 0.184 | Off: 0.020
21:00:48.679 -> Inferencia: anomaly (0.78)
21:00:48.679 -> Debug - Anomaly: 0.777 | Normal: 0.203 | Off: 0.020
21:00:48.711 -> Inferencia: anomaly (0.76)
21:00:48.711 -> Debug - Anomaly: 0.758 | Normal: 0.227 | Off: 0.016
21:00:48.775 -> Inferencia: anomaly (0.76)
21:00:48.775 -> Debug - Anomaly: 0.758 | Normal: 0.227 | Off: 0.016
21:00:48.807 -> Inferencia: anomaly (0.65)
21:00:48.807 -> Debug - Anomaly: 0.648 | Normal: 0.332 | Off: 0.020
21:00:48.839 -> Inferencia: anomaly (0.82)
21:00:48.839 -> Debug - Anomaly: 0.820 | Normal: 0.168 | Off: 0.012
21:00:48.871 -> Inferencia: anomaly (0.73)
21:00:48.871 -> Debug - Anomaly: 0.730 | Normal: 0.250 | Off: 0.020
21:00:48.903 -> Inferencia: anomaly (0.78)
21:00:48.935 -> Debug - Anomaly: 0.781 | Normal: 0.207 | Off: 0.016
21:00:48.967 -> Inferencia: anomaly (0.82)
21:00:48.967 -> Debug - Anomaly: 0.820 | Normal: 0.168 | Off: 0.012
21:00:48.999 -> Inferencia: anomaly (0.91)
21:00:48.999 -> Debug - Anomaly: 0.910 | Normal: 0.082 | Off: 0.004
21:00:49.031 -> Inferencia: anomaly (0.86)
21:00:49.031 -> Debug - Anomaly: 0.859 | Normal: 0.133 | Off: 0.008
21:00:49.063 -> Inferencia: anomaly (0.80)
21:00:49.063 -> Debug - Anomaly: 0.797 | Normal: 0.184 | Off: 0.016
21:00:49.127 -> Inferencia: anomaly (0.80)
21:00:49.127 -> Debug - Anomaly: 0.801 | Normal: 0.184 | Off: 0.016
21:00:49.127 -> ===== ANÁLISIS DE ESTADO DEL MOTOR =====
21:00:49.127 -> anomaly: 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: ANOMALIA 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: anomaly (0.87)
```

Inferencias - Golpes



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

Inferencias - Inclinación



```
17:57:44.215 -> [?] Inferencia: anomaly (0.75)
17:57:44.215 -> [?] Debug - Anomaly: 0.754 | Normal: 0.227 | Off: 0.020
17:57:44.248 -> [?] Inferencia: anomaly (0.84)
17:57:44.248 -> [?] Debug - Anomaly: 0.840 | Normal: 0.148 | Off: 0.012
17:57:44.280 -> [?] Inferencia: anomaly (0.64)
17:57:44.280 -> [?] Debug - Anomaly: 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: anomaly (0.64)
17:57:44.409 -> [?] Debug - Anomaly: 0.637 | Normal: 0.328 | Off: 0.035
17:57:44.441 -> [?] Inferencia: anomaly (0.60)
17:57:44.441 -> [?] Debug - Anomaly: 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 - Anomaly: 0.352 | Normal: 0.602 | Off: 0.047
17:57:44.572 -> [?] Inferencia: normal (0.60)
17:57:44.572 -> [?] Debug - Anomaly: 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 - Anomaly: 0.355 | Normal: 0.605 | Off: 0.035
17:57:44.733 -> [?] Inferencia: normal (0.69)
17:57:44.733 -> [?] Debug - Anomaly: 0.273 | Normal: 0.691 | Off: 0.035
17:57:44.767 -> [?] Inferencia: normal (0.74)
17:57:44.767 -> [?] Debug - Anomaly: 0.223 | Normal: 0.738 | Off: 0.039
17:57:44.799 -> [?] Inferencia: normal (0.74)
17:57:44.799 -> [?] Debug - Anomaly: 0.223 | Normal: 0.738 | Off: 0.039
17:57:44.832 -> [?] Inferencia: normal (0.74)
17:57:44.832 -> [?] Debug - Anomaly: 0.223 | Normal: 0.738 | Off: 0.039
17:57:44.864 -> [?] Inferencia: normal (0.69)
17:57:44.896 -> [?] Debug - Anomaly: 0.273 | Normal: 0.691 | Off: 0.035
17:57:44.929 -> [?] Inferencia: normal (0.74)
17:57:44.929 -> [?] Debug - Anomaly: 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: ANOMALIA DETECTADA - Revisar motor inmediatamente!
17:57:44.929 -> A 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 - Anomaly: 0.871 | Normal: 0.117 | Off: 0.008
21:22:11.365 -> Inferencia: anomaly (0.86)
21:22:11.365 -> Debug - Anomaly: 0.855 | Normal: 0.133 | Off: 0.012
21:22:11.397 -> Inferencia: anomaly (0.86)
21:22:11.397 -> Debug - Anomaly: 0.855 | Normal: 0.133 | Off: 0.012
21:22:11.462 -> Inferencia: anomaly (0.86)
21:22:11.462 -> Debug - Anomaly: 0.855 | Normal: 0.133 | Off: 0.012
21:22:11.496 -> Inferencia: anomaly (0.95)
21:22:11.496 -> Debug - Anomaly: 0.945 | Normal: 0.051 | Off: 0.004
21:22:11.529 -> Inferencia: anomaly (0.90)
21:22:11.529 -> Debug - Anomaly: 0.898 | Normal: 0.094 | Off: 0.008
21:22:11.561 -> Inferencia: anomaly (0.91)
21:22:11.561 -> Debug - Anomaly: 0.910 | Normal: 0.082 | Off: 0.008
21:22:11.594 -> Inferencia: anomaly (0.91)
21:22:11.594 -> Debug - Anomaly: 0.910 | Normal: 0.082 | Off: 0.008
21:22:11.659 -> Inferencia: anomaly (0.89)
21:22:11.659 -> Debug - Anomaly: 0.887 | Normal: 0.105 | Off: 0.008
21:22:11.692 -> Inferencia: anomaly (0.90)
21:22:11.692 -> Debug - Anomaly: 0.902 | Normal: 0.094 | Off: 0.004
21:22:11.725 -> Inferencia: anomaly (0.84)
21:22:11.725 -> Debug - Anomaly: 0.844 | Normal: 0.148 | Off: 0.008
21:22:11.759 -> Inferencia: anomaly (0.88)
21:22:11.759 -> Debug - Anomaly: 0.875 | Normal: 0.117 | Off: 0.008
21:22:11.790 -> Inferencia: anomaly (0.86)
21:22:11.823 -> Debug - Anomaly: 0.855 | Normal: 0.133 | Off: 0.012
21:22:11.856 -> Inferencia: anomaly (0.90)
21:22:11.856 -> Debug - Anomaly: 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 -> anomaly: 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 ->
21:22:11.888 -> Inferencia: anomaly (0.90)
```

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

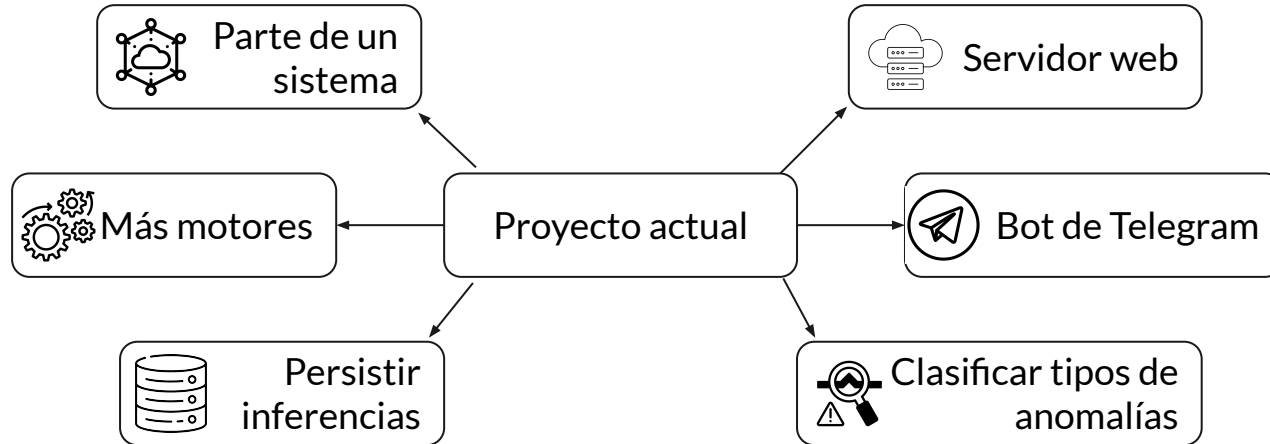


Ideal para contextos sin
conectividad y bajo costo



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 [DALI-3](#)