1. Introduction to TinyML

Enabling Edge Intelligence on Tiny Devices

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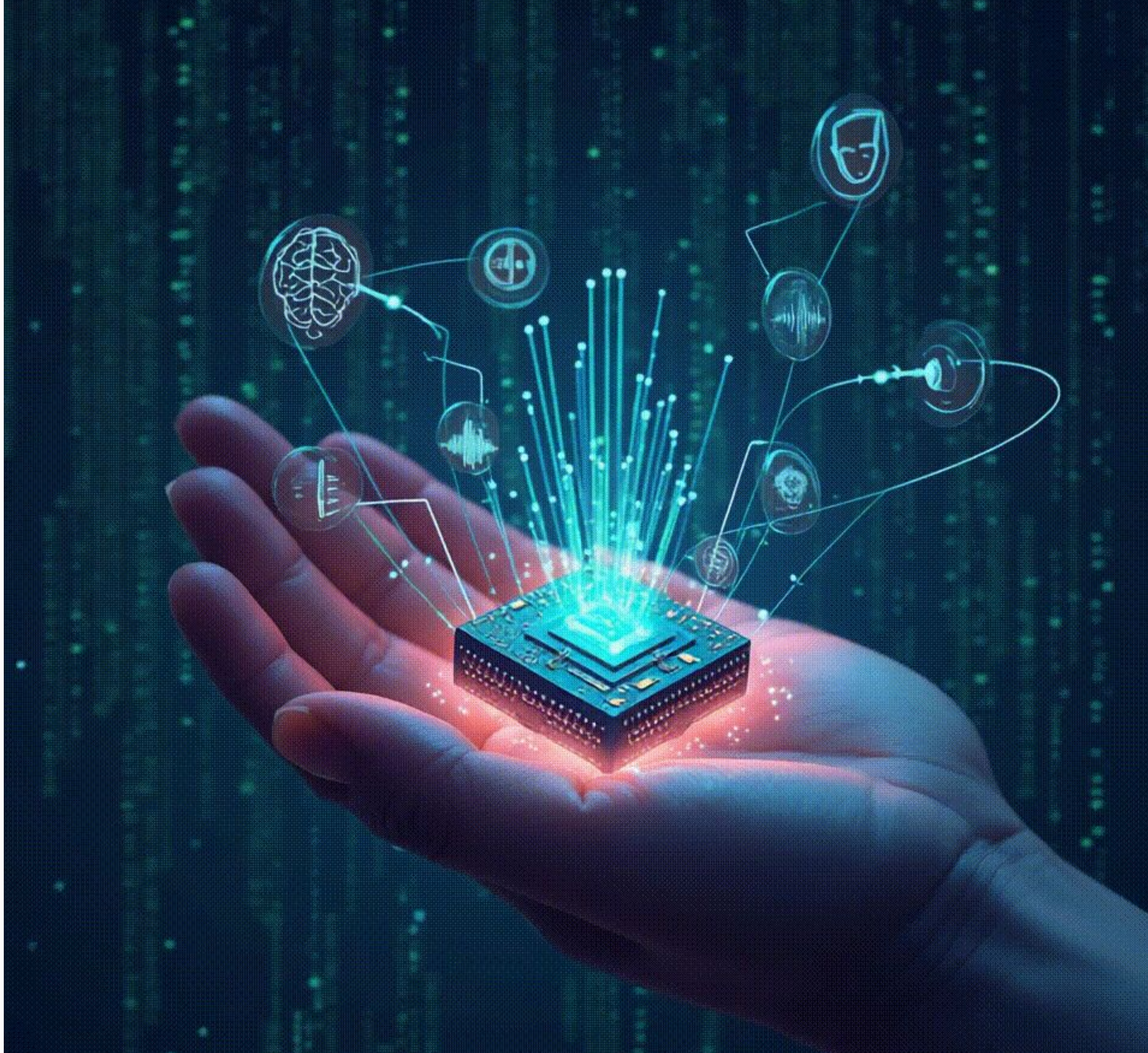
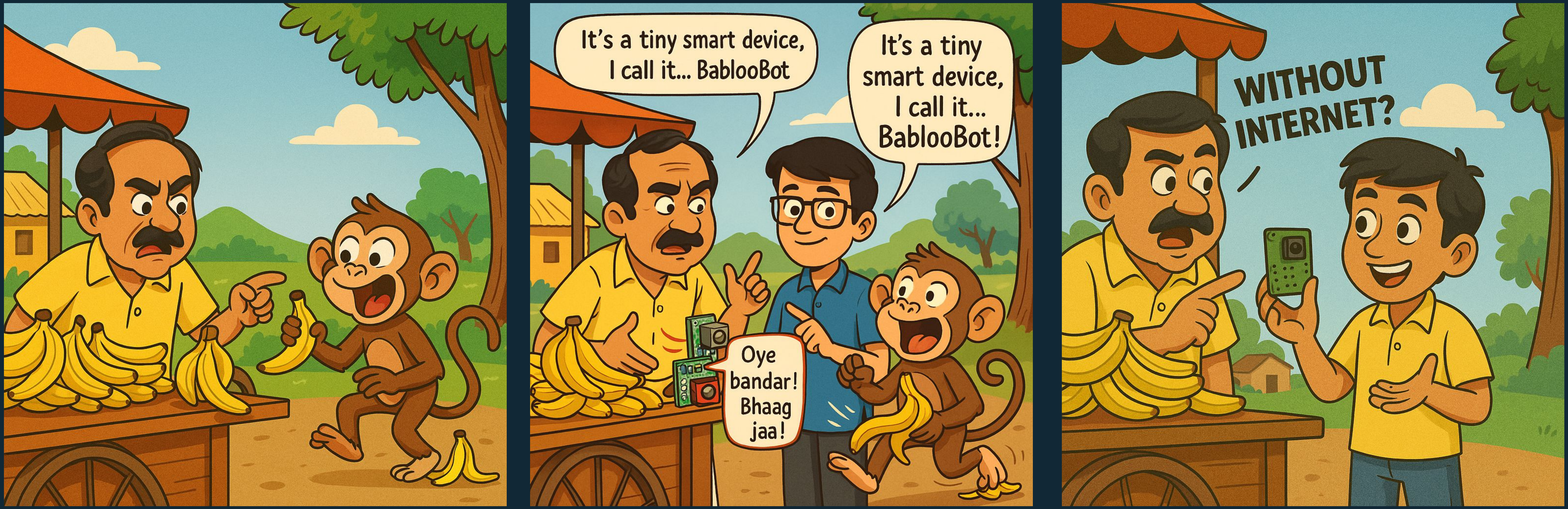


TinyML: Definition

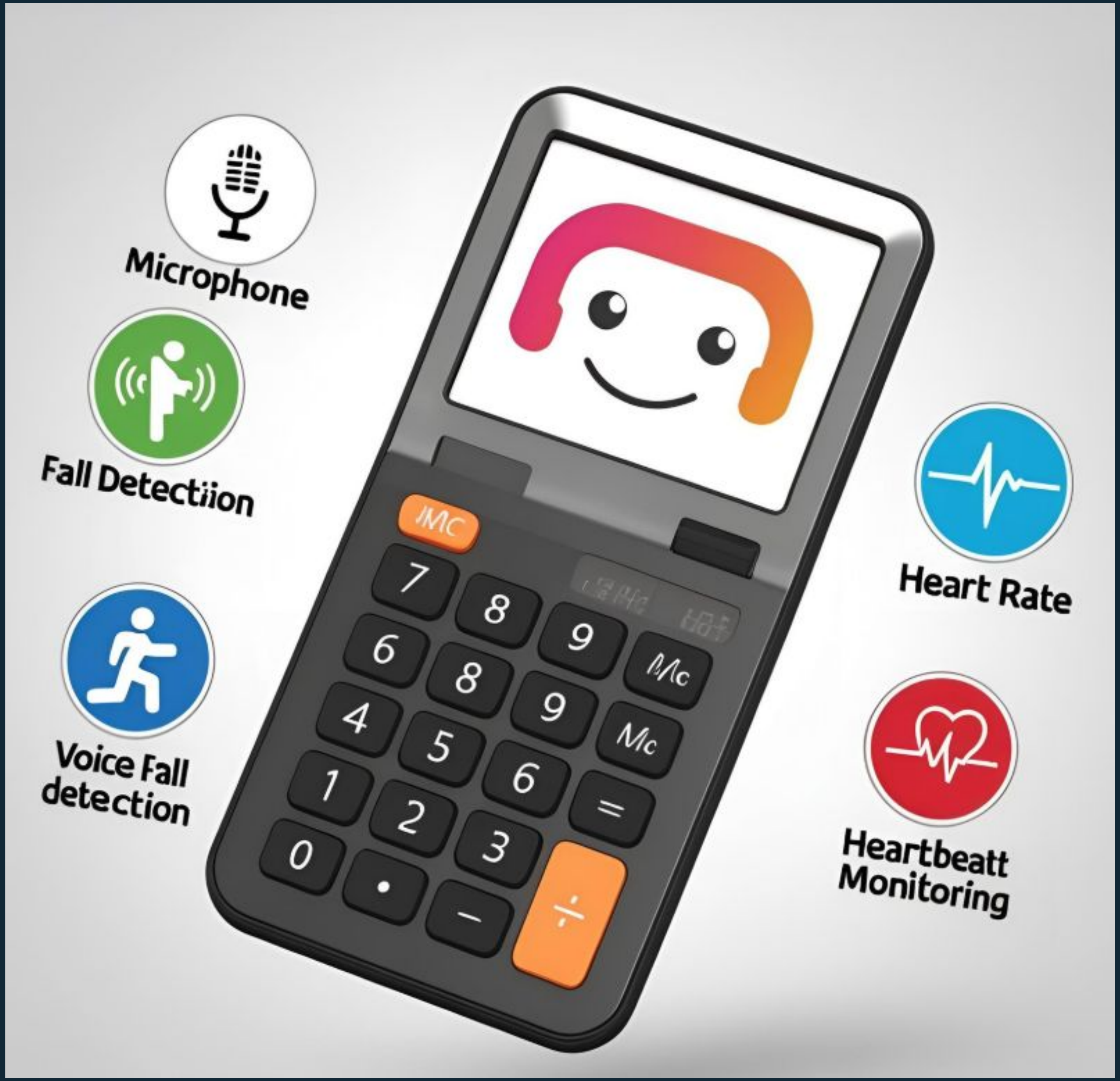
TinyML runs machine learning on tiny, low-power devices for smart tasks at the edge.

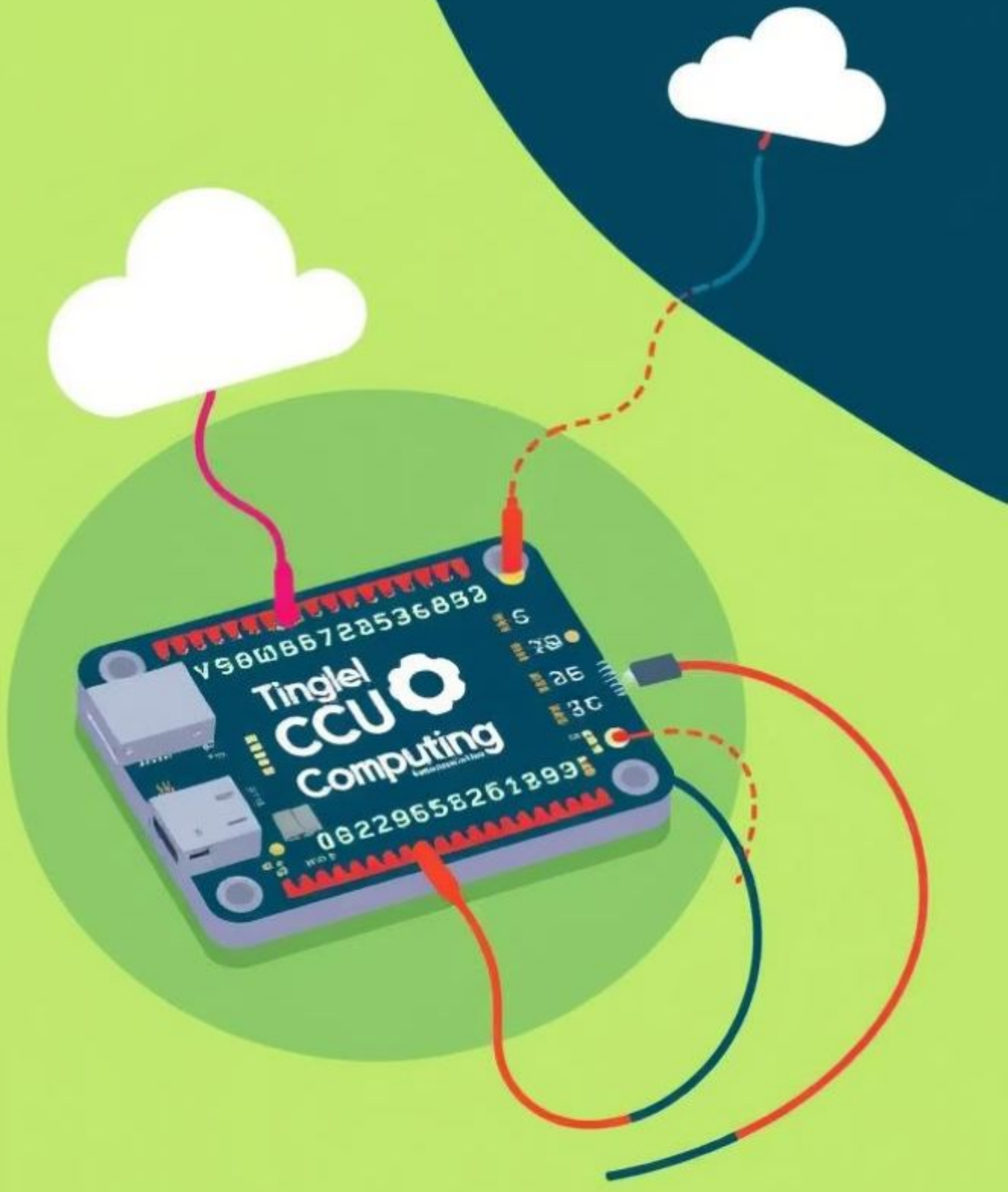
TinyML: Small but Mighty!

TinyML is like an ant with the strength of an elephant — tiny devices doing powerful AI tasks!


It's a tiny smart device, I call it... BablooBot
It's a tiny smart device, I call it... BablooBot!
Oye bandar! Bhaag jaa!
WITHOUT INTERNET?

Visualization?





TinyML Characteristics

On-device Learning

Machine learning performed on microcontrollers and edge devices.

Low Power Use

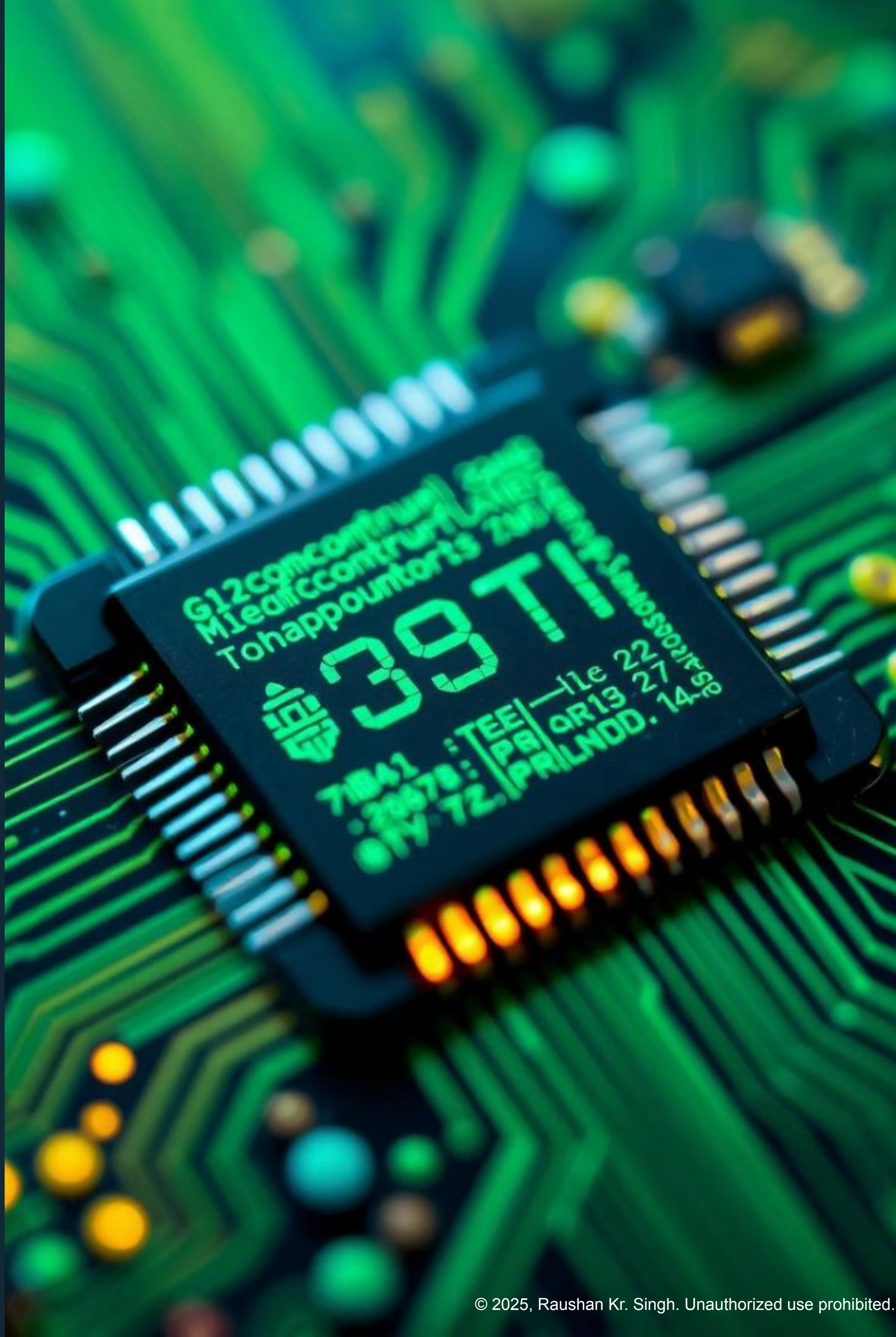
Consumes milliwatts or less, ideal for battery-powered devices.

Small Memory

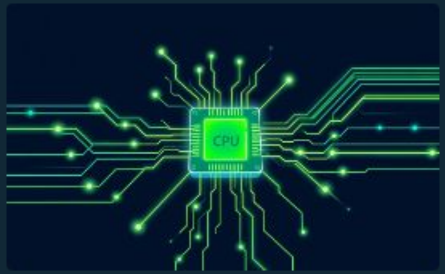
Runs on devices with only kilobytes of memory.

Cost-Effective

Enables scalable deployment with minimal expense.



The Importance of Edge AI



Low Latency

Processes data 10x faster than cloud

Privacy

Data stays on device, securing privacy

Reliability

Operates offline without interruptions

Cost and Bandwidth

Reduces network use and expenses

Real-Time Actions

Enables instant decisions at the source

Challenges in constrained ML

Limited Compute Power

Tiny devices have low processing capabilities, making it hard to run complex models.

Memory Constraints

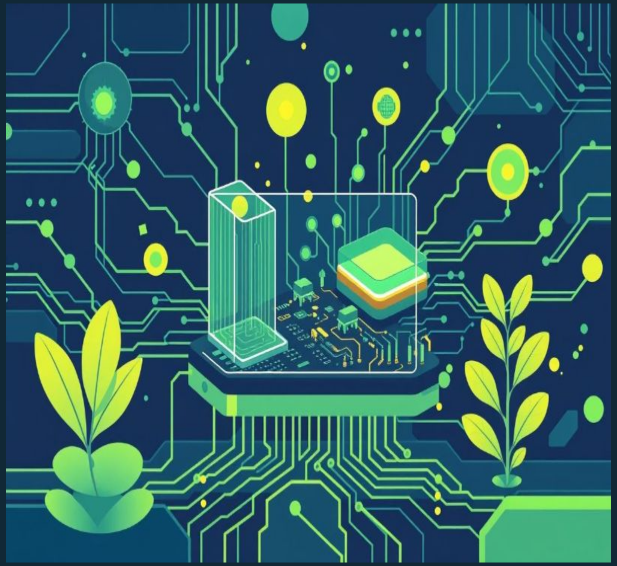
Very limited RAM and storage restrict model size and the amount of data processing.

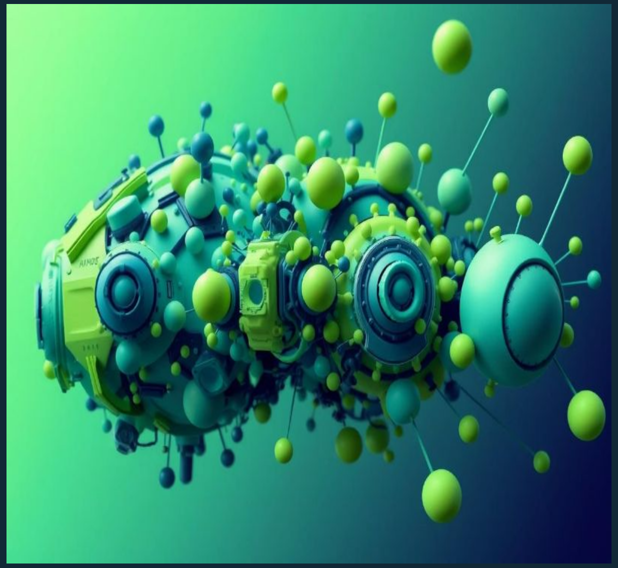
Energy Efficiency

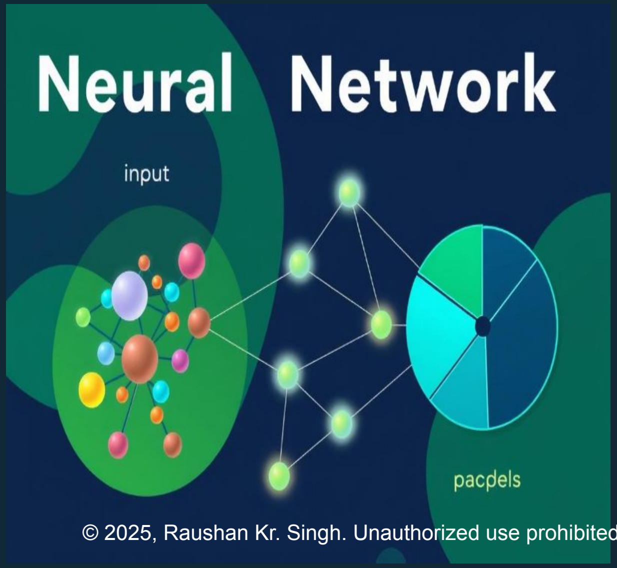
Battery-powered devices need low-power ML to last longer.

Latency & Real-Time Processing

Real-time apps need fast responses despite limited resources.







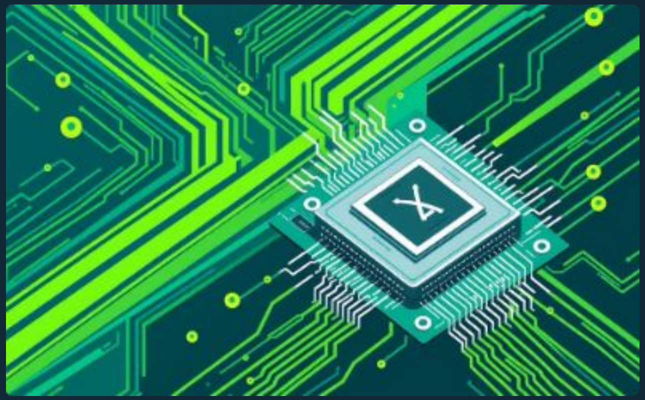
Key Techniques in TinyML

Model Compression

Pruning, quantization, and knowledge distillation reduce model size effectively.

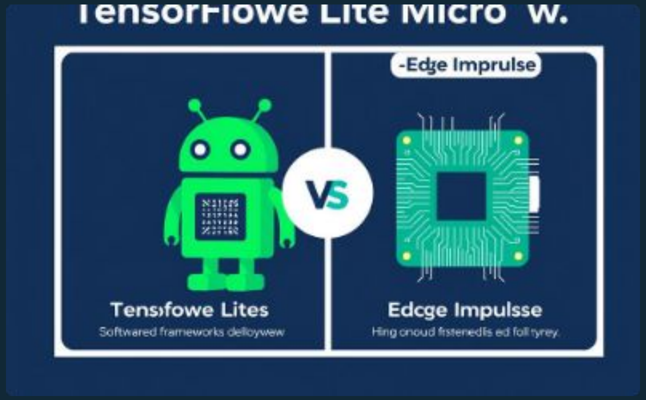
Efficient Inference

Optimized kernels and fixed-point arithmetic enhance speed and efficiency.



Hardware Acceleration

Use of specialized microcontrollers and ASICs to boost performance.



Software Frameworks

Frameworks like TensorFlow Lite Micro and Edge Impulse enable deployment.

TinyML: Small Tech, Huge Impact

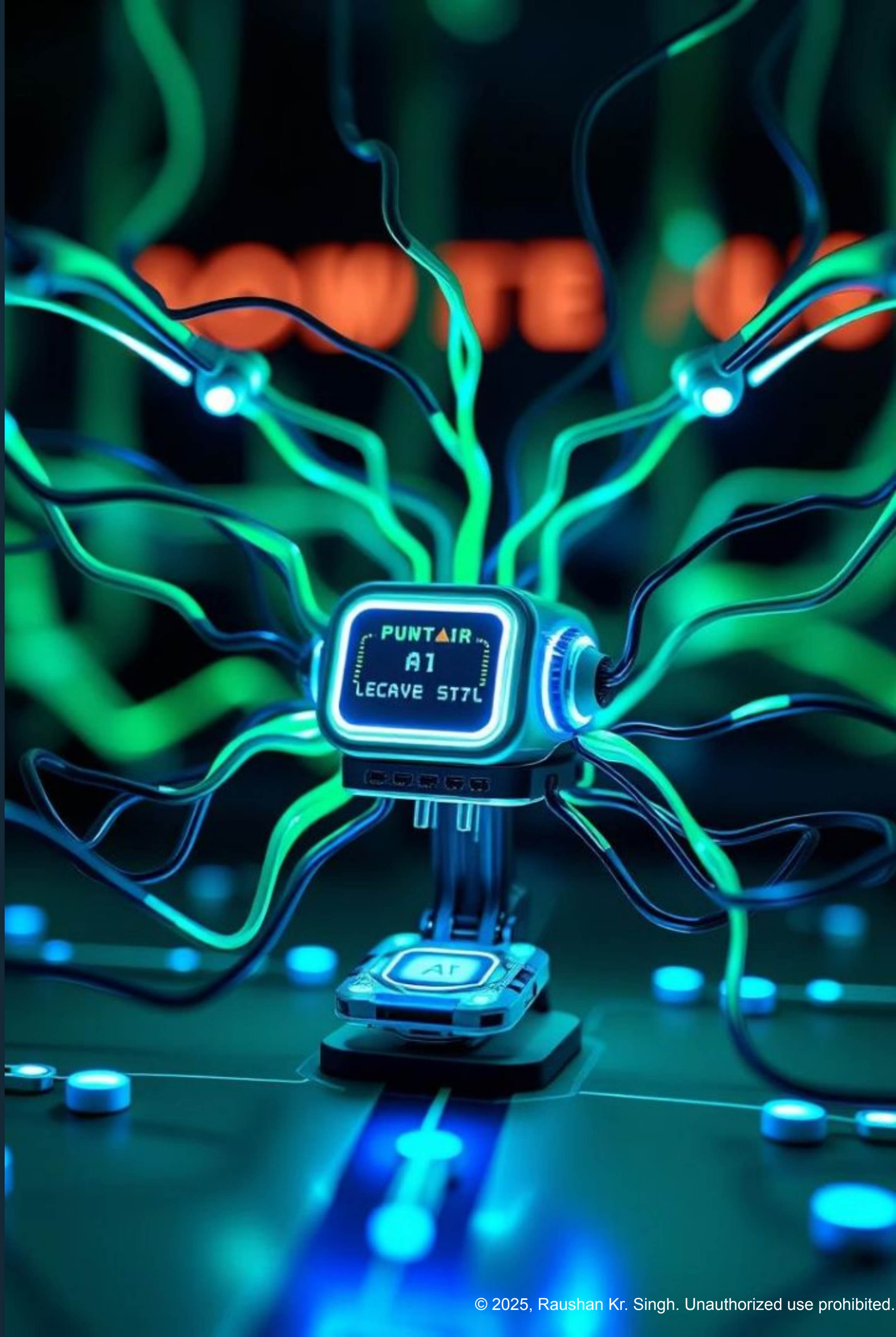
IoT (Smart Sensors)

Healthcare (Wearables, Monitoring)

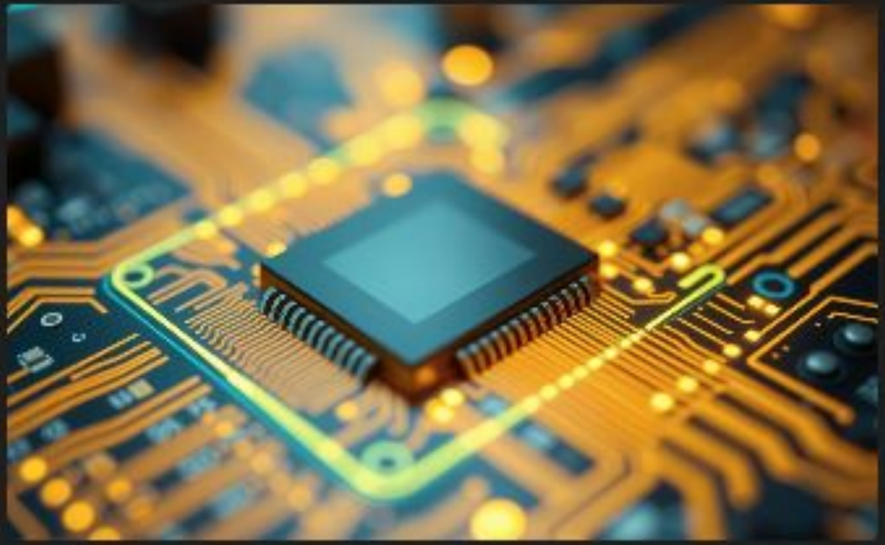
Agriculture (Smart Farming)

Industry 4.0 (Predictive Maintenance)

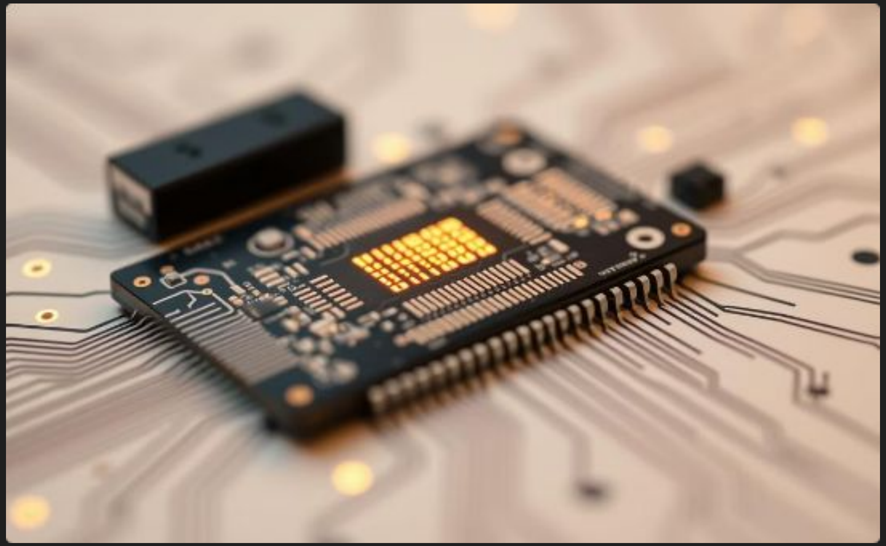
2023 - 1.47 : 2030 - 10.80 billion USD



TinyML Applications

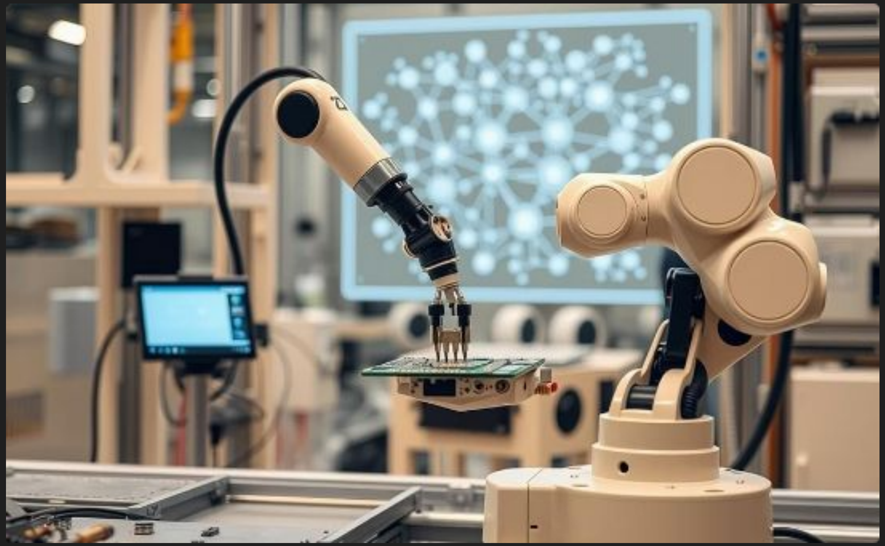


Applications of TinyML: AI at the Edge



Tiny devices powered by microcontrollers enable efficient machine learning.

Minimal resource usage empowers intelligent devices on the edge.



Embedded AI revolutionizes industries by running on edge devices directly.

Applications of TinyML

Industrial IoT

Predictive maintenance cuts downtime by 20%.

Healthcare

Wearables provide personalized health monitoring.

Smart Agriculture

Monitors crops to optimize yield and resources.

Voice Recognition

Embedded systems detect keywords efficiently.

Fraud Detection

Real-time anomaly detection in financial services.

Smart Agriculture: Optimizing Crop Yield

Precision Farming

Real-time analytics improve water use and crop care.

Soil Moisture Sensors

Uses TensorFlow Lite Micro on ARM Cortex-M4. Cuts water use by 30%.

Disease Detection

Image recognition detects crop diseases with 90% accuracy.

Wearable Health Monitoring: Personalized Healthcare

Continuous Tracking

On-device heart rate anomaly detection using accelerometer data on Nordic nRF52.

Health Benefits

Alert systems reduce hospital readmissions by 15% and analyze sleep patterns clinically.

Predictive Maintenance (Industry 4.0): Preventing Downtime

1 Vibration Analysis

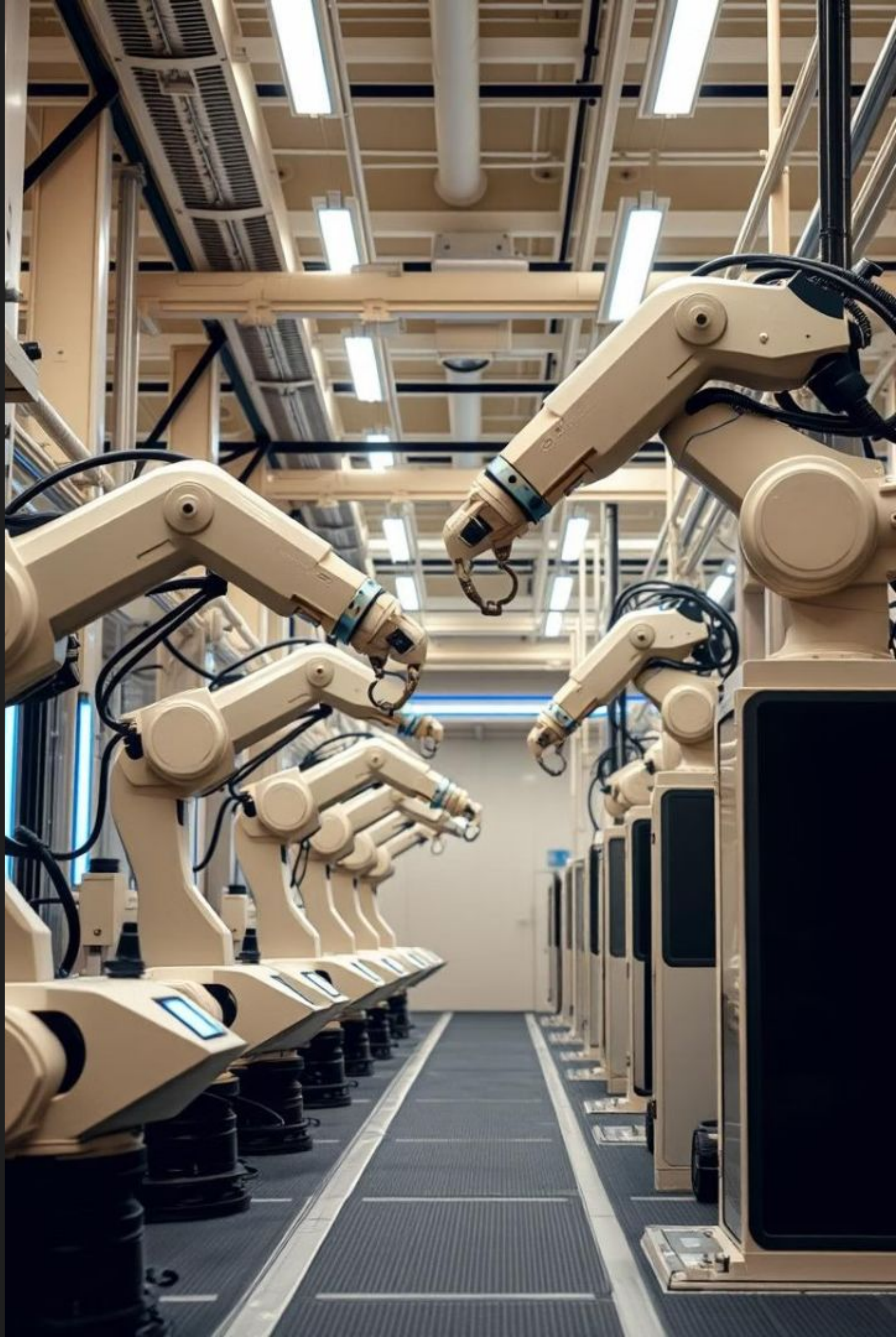
Using STM32 microcontrollers to monitor machine health.

2 Failure Prediction

Detects equipment failures 2 weeks ahead with 95% accuracy.

3 Cost Reduction

Reduces maintenance expenses by 25%, boosts uptime by 15%.



Smart Home Automation: Intelligent Living Spaces

Voice Recognition

Controls appliances using Raspberry Pi Pico with offline AI.

Privacy & Reliability

Fully offline processing ensures data security and uptime.

Energy Savings

Optimizes energy use for over $100 annual savings.

Environmental Monitoring: Protecting Our Planet

Air Quality

Gas sensors on ESP32 spot pollution hotspots with 98% accuracy.

Fire Detection

Acoustic sensors detect forest fires, cutting response times by 40%.

Wildlife Conservation: Safeguarding Biodiversity

1

Species Identification

Audio classification detects animals with TinyML on low-power sensors.

2

Poaching Alerts

Real-time monitoring triggers alarms with 99% accuracy.

3

Conservation Impact

Supports protection efforts and reduces human-wildlife conflicts.

Baby Cry Mood Detection

TinyML enables accurate classification of baby cries into moods like hunger, discomfort, pain, or need for attention, helping caregivers respond promptly.

Running on low-power microcontrollers with built-in microphones, it operates efficiently without cloud connectivity, preserving privacy and battery life.

This application improves infant care by reducing response times and easing caregiver stress through real-time edge intelligence.

TinyML Utilities

1. **Google Coral Dev Board Micro**

   Platform for TinyML prototyping and development.

2. **Edge Impulse Studio**

   Builds and deploys ML models on embedded devices.

3. **TensorFlow Lite Micro**

   Runs ML models efficiently on microcontrollers.

4. **ARM Ethos-U55 microNPU**

   Accelerates neural network inference on edge.

The Future of TinyML: Limitless Possibilities

Edge Intelligence

AI integrated with 5G and IoT for real-time processing.

Scalable Solutions

Cost-effective AI enabling global deployment.

Democratized AI

Making smart technology accessible worldwide.

Future Trends in TinyML

1

Wider Adoption

Growth in automotive, consumer electronics, healthcare.

2

Efficient Hardware

Development of advanced tools for TinyML tasks.

3

Edge and 5G Integration

Smoother connection between edge devices and networks.

4

Security Focus

Enhanced privacy and protection in deployments.

5

Democratization

More learning resources and open projects available.

Key Takeaways

- ★ TinyML brings AI to low-power edge devices.
- ★ Enables real-time, offline, and private inference.
- ★ Designed for ultra-low memory and power usage.
- ★ Used in healthcare, IoT, agriculture, and voice systems.
- ★ Tools: TensorFlow Lite Micro, Edge Impulse, ARM NPUs.
- ★ Market growing rapidly — $10.8B by 2030.
- ★ Future trends: adoption, hardware, 5G, security, and accessibility.

Assignment

NDSS About 2026 Symposium 2025 Symposium Previous Events Submissions

TinyML meets IoBT against Sensor Hacking

Raushan Kumar Singh (IIT Ropar), Sudeepta Mishra (IIT Ropar)

Modern technology is advancing on many different levels, and the battlefield is no exception. India has 15000 km of lengthy land borders shared with many other neighboring countries, and only 5 of the 29 states in India do not have any shared international borders or coastlines. Wire fences and conventional sensor-based systems are used to protect terrestrial borders. Wire fences, being the only line of defense against intrusions at most unmanned borders, result in frequent cases of unreported incursion, smuggling, and human trafficking. Typically, intruders cut the fence to gain access to Indian land, and sensor-based systems are prone to false alarms due to animal movements. We propose combining the intelligence of Tiny Machine Learning (TinyML) with the communication capability of IoT to make borders safer and intrusion more challenging. To learn the typical fence movements from natural causes, we use TinyML. Our learning technique is created explicitly to differentiate between regular fence movement and suspicious fence disturbance. The system is efficient enough to detect metal fence cuts and trespassing carefully. With the aid of online learning environments, the sophisticated TinyML microcontroller's built-in accelerometer can differentiate between different movement patterns. To identify the most effective defense against sensor-level attacks, we conducted tests to gauge the tolerance levels of conventional microcontroller sensor systems against TinyML-powered microcontrollers when exposed to Electromagnetic Pulse (EMP) based sensor hacking attempts. To the best of our knowledge, this is the first research conducted for the Identification of the best suite sensor system for high-precision Internet of Battlefield Things (IoBT) applications. During the real-time model test, the system is found to be 95.4% accurate and readily deployable on TinyML microcontrollers.

Paper

Thank You for Your Attention