SocratiQ with tinyML

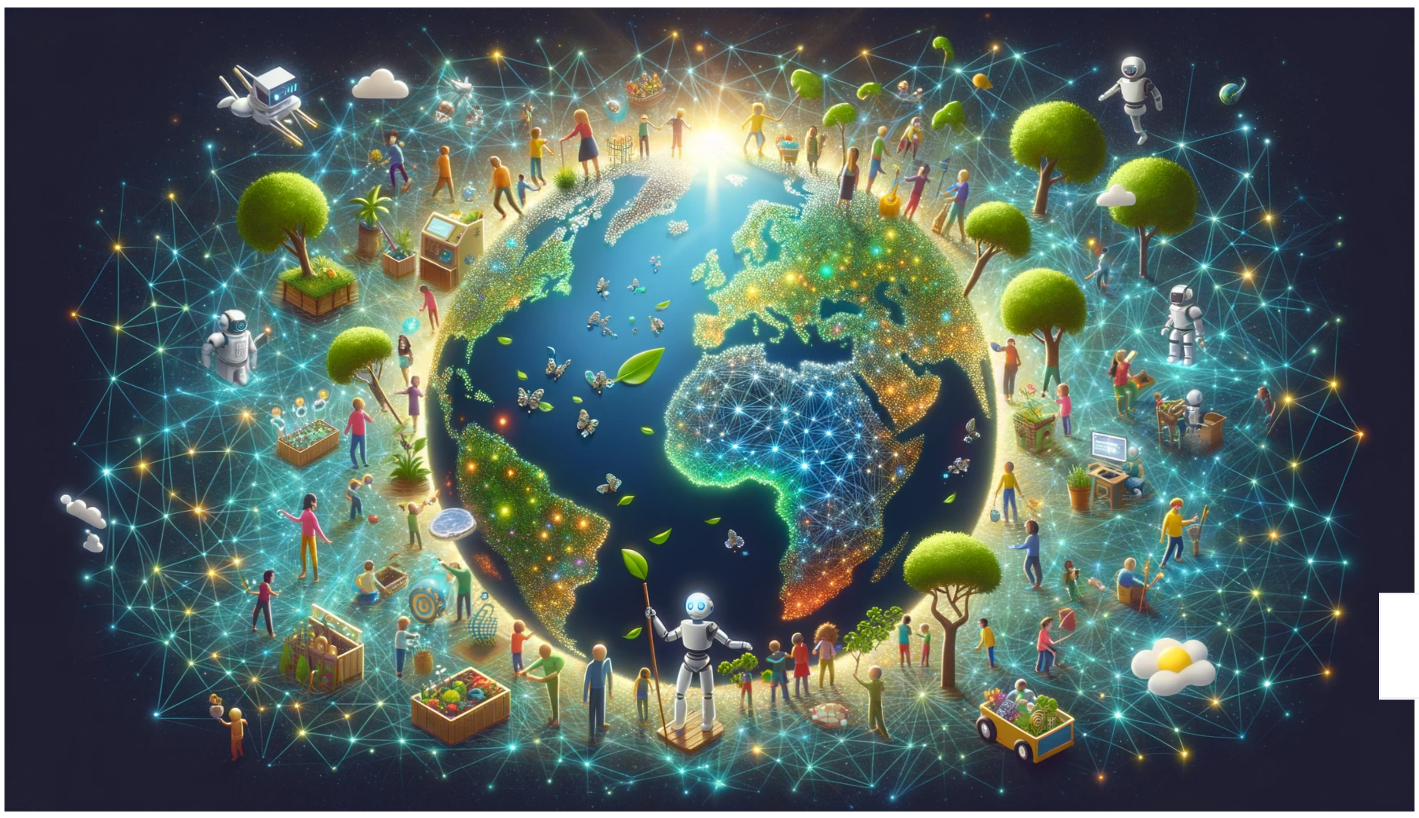
What is SocratiQ?

SocratiQ is an AI Generative Learning Assistant, designed to make learning r efficient, engaging and accessible. We welcome your Feedback. Learn more a SocratiQ.

1 2 3

19 AI for Good

Resources: Slides, Videos, Exercises, Labs



DALL·E 3 Prompt: Illustration of planet Earth wrapped in shimmering neural networks, with diverse humans and AI robots working together on various projects like planting trees, cleaning the oceans, and developing sustainable energy solutions. The positive and hopeful atmosphere represents a united effort to create a better future.

By aligning AI progress with human values, goals, and ethics, the ultimate goal of ML systems (at any scale) is to be a technology that reflects human principles and aspirations. Initiatives under "AI for Good" promote the development of AI to tackle the UN Sustainable Development Goals (SDGs) using embedded AI technologies, expanding access to AI education, amongst other things. While it is now clear that AI will be an instrumental part of progress towards the SDGs, its adoption and impact are limited by the immense power consumption, strong connectivity requirements, and high costs of cloud-based deployments. TinyML can circumvent many of these issues by allowing ML models to run on low-cost and low-power microcontrollers.

good way to wrap up book

> The "AI for Good" movement is critical in cultivating a future where an AI-empowered society is more just, sustainable, and prosperous for all humanity.

why weird capitalization?

great chp, easy to understand, cool examples.

one remaining thought (not for this chp) - we've read abt env. implications of AI; what are potential areas of warfare + weaponry dev. will AI effect? or creative fields? or education?

Mindfulness break

Explain

Find rel

Summarize this page

Ask anything...

Information provided here may not always be ac

Learning Objectives

- Understand how TinyML can help advance the UN Sustainable Development Goals in health, agriculture, education, and the environment.
- Recognize the versatility of TinyML for enabling localized, low-cost solutions tailored to community needs.

Connected

- Consider the challenges of adopting TinyML globally, such as limited training, data constraints, accessibility, and cultural barriers.
- Appreciate the importance of collaborative, ethical approaches to develop and deploy TinyML to serve local contexts best.
- Recognize the potential of TinyML, if responsibly implemented, to promote equity and empower underserved populations worldwide.

19.1 Introduction

To give ourselves a framework around which to think about AI for social good, we will be following the UN Sustainable Development Goals (SDGs). The UN SDGs are a collection of 17 global goals, shown in Figure 19.1, adopted by the United Nations in 2015 as part of the 2030 Agenda for Sustainable Development. The SDGs address global challenges related to poverty, inequality, climate change, environmental degradation, prosperity, and peace and justice.

What is special about the SDGs is that they are a collection of interlinked objectives designed to serve as a "shared blueprint for peace and prosperity for people and the planet, now and into the future." The SDGs emphasize sustainable development's interconnected environmental, social, and economic aspects by putting sustainability at their center.

A recent study (Vinuesa et al. 2020) highlights the influence of AI on all aspects of sustainable development, particularly on the 17 Sustainable Development Goals (SDGs) and 169 targets internationally defined in the 2030 Agenda for Sustainable Development. The study shows that AI can act as an enabler for 134 targets through technological improvements, but it also highlights the challenges of AI on some targets. The study shows that AI can benefit 67 targets when considering AI and societal outcomes. Still, it also warns about the issues related to the implementation of AI in countries with different cultural values and wealth.

Vinuesa, Ricardo, Hossein Azizpour, Iolanda Leite, Madeline Balaam, Virginia Dignum, Sami Domisch, Anna Felländer, Simone Daniela Langhans, Max Tegmark, and Francesco Fuso Nerini. 2020. "The Role of Artificial Intelligence in Achieving the Sustainable Development Goals." *Nat Commun* 11 (1): 1–10. https://doi.org/10.1038/s41467-019-14108-y

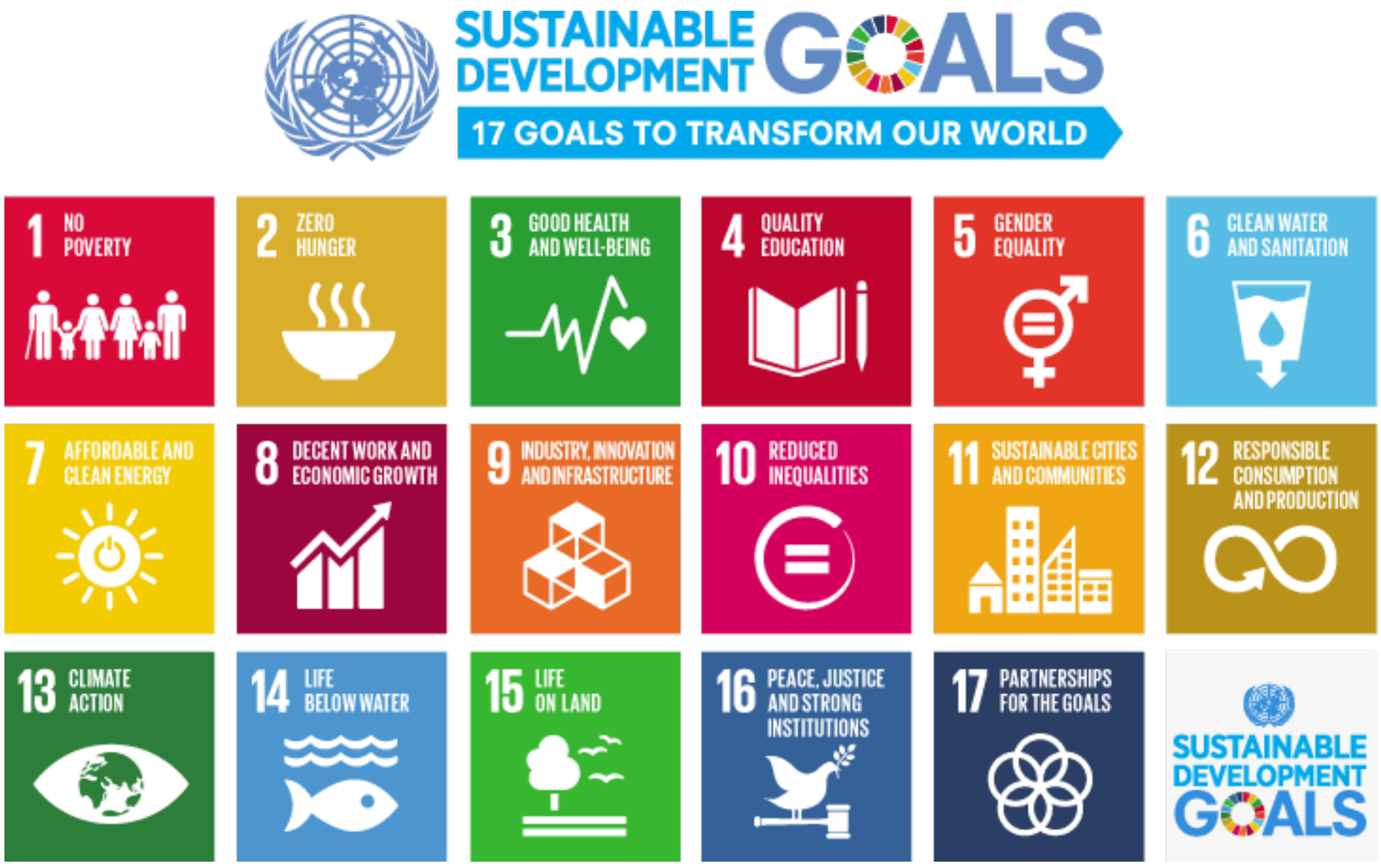


Figure 19.1: United Nations Sustainable Development Goals (SDG). Credit: United Nations.

In our book's context, TinyML could help advance at least some of these SDG goals.

- **Goal 1 - No Poverty:** TinyML could help provide low-cost solutions for crop monitoring to improve agricultural yields in developing countries.
- **Goal 2 - Zero Hunger:** TinyML could enable localized and precise crop health monitoring and disease detection to reduce crop losses.
- **Goal 3 - Good Health and Wellbeing:** TinyML could help enable low-cost medical diagnosis tools for early detection and prevention of diseases in remote areas.
- **Goal 6 - Clean Water and Sanitation:** TinyML could monitor water quality and detect contaminants to ensure Access to clean drinking water.
- **Goal 7 - Affordable and Clean Energy:** TinyML could optimize energy consumption and enable predictive maintenance for renewable energy infrastructure.
- **Goal 11 - Sustainable Cities and Communities:** TinyML could enable intelligent traffic management, air quality monitoring, and optimized resource management in smart cities.
- **Goal 13 - Climate Action:** TinyML could monitor deforestation and track reforestation efforts. It could also help predict extreme weather events.

The portability, lower power requirements, and real-time analytics enabled by TinyML make it well-suited for addressing several sustainability challenges developing regions face. The widespread deployment of power solutions has the potential to provide localized and cost-effective monitoring to help achieve some of the UN's SDGs. In the rest of the sections, we will dive into how TinyML is useful across many sectors that can address the UN SDGs.

19.2 Agriculture

Agriculture is essential to achieving many of the UN Sustainable Development Goals, including eradicating Hunger and malnutrition, promoting economic growth, and using natural resources sustainably. TinyML can be a valuable tool to help advance sustainable agriculture, especially for smallholder farmers in developing regions.

TinyML solutions can provide real-time monitoring and data analytics for crop health and growing conditions - all without reliance on connectivity infrastructure. For example, low-cost camera modules connected to microcontrollers can monitor for disease, pests, and nutritional deficiencies. TinyML algorithms can analyze the images to detect issues early before they spread and damage yields. Precision monitoring can optimize inputs like water, fertilizer, and pesticides - improving efficiency and sustainability monitoring can optimize inputs like water, fertilizer, and pesticides – improving efficiency and sustainability.

Other sensors, such as GPS units and accelerometers, can track microclimate conditions, soil humidity, and livestock wellbeing. Local real-time data helps farmers respond and adapt better to changes in the field. TinyML analytics at the edge avoids lag, network disruptions, and the high data costs of cloud-based systems. Localized systems allow customization of specific crops, diseases, and regional issues.

Widespread TinyML applications can help digitize smallholder farms to increase productivity, incomes, and resilience. The low cost of hardware and minimal connectivity requirements make solutions accessible. Projects across the developing world have shown the benefits:

- Microsoft's FarmBeats project is an end-to-end approach to enable data-driven farming by using low-cost sensors, drones, and vision and machine learning algorithms. The project aims to solve the problem of limited adoption of technology in farming due to the need for more power and internet connectivity in farms and the farmers' limited technology savviness. The project aims to increase farm productivity and reduce costs by coupling data with farmers' knowledge and intuition about their farms. The project has successfully enabled actionable insights from data by building artificial intelligence (AI) or machine learning (ML) models based on fused data sets.
- In Sub-Saharan Africa, off-the-shelf cameras and edge AI have cut cassava disease losses from 40% to 5%, protecting a staple crop (Ramcharan et al. 2017).
- In Indonesia, sensors monitor microclimates across rice paddies, optimizing water usage even with erratic rains (Tirtalistyani, Murtiningrum, and Kanwar 2022).

Ramcharan, Amanda, Kelsee Baranowski, Peter McCloskey, Babuali Ahmed, James Legg, and David P. Hughes. 2017. "Deep Learning for Image-Based Cassava Disease Detection." *Front. Plant Sci.* 8 (October): 1852. https://doi.org/10.3389/fpls.2017.01852.

Tirtalistyani, Rose, Murtiningrum Murtiningrum, and Rameshwar S. Kanwar. 2022. "Indonesia Rice Irrigation System: Time for Innovation." *Sustainability* 14 (19): 12477. https://doi.org/10.3390/su141912477.

With greater investment and integration into rural advisory services, TinyML could transform small-scale agriculture and improve farmers' livelihoods worldwide. The technology effectively brings the benefits of precision agriculture to disconnected regions most in need.

Exercise 19.1: Crop Yield Modeling

19.3 Healthcare

19.3.1 Expanding Access

Universal health coverage and quality care remain out of reach for millions worldwide. In many regions, more medical professionals are required to Access basic diagnosis and treatment. Additionally, healthcare infrastructure like clinics, hospitals, and utilities to power complex equipment needs to be improved. These gaps disproportionately impact marginalized communities, exacerbating health disparities.

TinyML offers a promising technological solution to help expand Access to quality healthcare globally. TinyML refers to the ability to deploy machine learning algorithms on microcontrollers, tiny chips with processing power, memory, and connectivity. TinyML enables real-time data analysis and intelligence in low-powered, compact devices.

This creates opportunities for transformative medical tools that are portable, affordable, and accessible. TinyML software and hardware can be optimized to run even in resource-constrained environments. For example, a TinyML system could analyze symptoms or make diagnostic predictions using minimal computing power, no continuous internet connectivity, and a battery or solar power source. These capabilities can bring medical-grade screening and monitoring directly to underserved patients.

19.3.2 Early Diagnosis

Early detection of diseases is one major application. Small sensors paired with TinyML software can identify symptoms before conditions escalate or visible signs appear. For instance, cough monitors with embedded machine learning can pick up on acoustic patterns indicative of respiratory illness, malaria, or tuberculosis. Detecting diseases at onset improves outcomes and reduces healthcare costs.

A detailed example could be given for TinyML monitoring pneumonia in children. Pneumonia is a leading cause of death for children under 5, and detecting it early is critical. A startup called Respira xColabs has developed a low-cost wearable audio sensor that uses TinyML algorithms to analyze coughs and identify symptoms of respiratory illnesses like pneumonia. The device contains a microphone sensor and microcontroller that runs a neural network model trained to classify respiratory sounds. It can identify features like wheezing, crackling, and stridor that may indicate pneumonia. The device is designed to be highly accessible - it has a simple strap, requires no battery or charging, and results are provided through LED lights and audio cues.

Another example involves researchers at UNIFEI in Brazil who have developed a low-cost device that leverages TinyML to monitor heart rhythms. Their innovative solution addresses a critical need - atrial fibrillation and other heart rhythm abnormalities often go undiagnosed due to the prohibitive cost and limited availability of screening tools. The device overcomes these barriers through its ingenious design. It uses an off-the-shelf microcontroller that costs only a few dollars, along with a basic pulse sensor. By

minimizing complexity, the device becomes accessible to under-resourced populations. The TinyML minimizing complexity, the device becomes accessible to under-resourced populations. The TinyML algorithm running locally on the microcontroller analyzes pulse data in real-time to detect irregular heart rhythms. This life-saving heart monitoring device demonstrates how TinyML enables powerful AI capabilities to be deployed in cost-effective, user-friendly designs.

TinyML's versatility also shows promise for tackling infectious diseases. Researchers have proposed applying TinyML to identify malaria-spreading mosquitoes by their wingbeat sounds. When equipped with microphones, small microcontrollers can run advanced audio classification models to determine mosquito species. This compact, low-power solution produces results in real time, suitable for remote field use. By making entomology analytics affordable and accessible, TinyML could revolutionize monitoring insects that endanger human health. TinyML is expanding healthcare access for vulnerable communities from heart disease to malaria.

19.3.3 Infectious Disease Control

Mosquitoes remain the most deadly disease vector worldwide, transmitting illnesses that infect over one billion people annually ("Vector-Borne Diseases," n.d.). Diseases like malaria, dengue, and Zika are especially prevalent in resource-limited regions lacking robust infrastructure for mosquito control. Monitoring local mosquito populations is essential to prevent outbreaks and properly target interventions.

"Vector-Borne Diseases." n.d. https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases.

Traditional monitoring methods are expensive, labor-intensive, and difficult to deploy remotely. The proposed TinyML solution aims to overcome these barriers. Small microphones coupled with machine learning algorithms can classify mosquitoes by species based on minute differences in wing oscillations. The TinyML software runs efficiently on low-cost microcontrollers, eliminating the need for continuous connectivity.

A collaborative research team from the University of Khartoum and the ICTP is exploring an innovative solution using TinyML. In a recent paper, they presented a low-cost device that can identify disease-spreading mosquito species through their wing beat sounds (Altayeb, Zennaro, and Rovai 2022).

Altayeb, Moez, Marco Zennaro, and Marcelo Rovai. 2022. "Classifying Mosquito Wingbeat Sound Using TinyML." In *Proceedings of the 2022 ACM Conference on Information Technology for Social Good*, 132–37. ACM. https://doi.org/10.1145/3524458.3547258.

This portable, self-contained system shows great promise for entomology. The researchers suggest it could revolutionize insect monitoring and vector control strategies in remote areas. TinyML could significantly bolster malaria eradication efforts by providing cheaper, easier mosquito analytics. Its versatility and minimal power needs make it ideal for field use in isolated, off-grid regions with scarce resources but high disease burden.

19.3.4 TinyML Design Contest in Healthcare

The first TinyML contest in healthcare, TDC'22 (Jia et al. 2023), was held in 2022 to motivate participating teams to design AI/ML algorithms for detecting life-threatening ventricular arrhythmias (VAs) and deploy them on Implantable Cardioverter Defibrillators (ICDs). VAs are the main cause of sudden cardiac death (SCD). People at high risk of SCD rely on the ICD to deliver proper and timely defibrillation treatment (i.e., shocking the heart back into normal rhythm) when experiencing life-threatening VAs.

Jia, Zhenge, Dawei Li, Xiaowei Xu, Na Li, Feng Hong, Lichuan Ping, and Yiyu Shi. 2023. "Life-Threatening Ventricular Arrhythmia Detection Challenge in Implantable Cardioverterdefibrillators." *Nature Machine Intelligence* 5 (5): 554–55. https://doi.org/10.1038/s42256-023-00659-9.

An on-device algorithm for early and timely life-threatening VA detection will increase the chances of survival. The proposed AI/ML algorithm needed to be deployed and executed on an extremely low-power and resource-constrained microcontroller (MCU) (a $10 development board with an ARM Cortex-M4 core at 80 MHz, 256 kB of flash memory and 64 kB of SRAM). The submitted designs were evaluated by metrics measured on the MCU for (1) detection performance, (2) inference latency, and (3) memory occupation by the program of AI/ML algorithms.

The champion, GaTech EIC Lab, obtained 0.972 in F_β (F1 score with a higher weight to recall), 1.747 ms in latency, and 26.39 kB in memory footprint with a deep neural network. An ICD with an on-device VA detection algorithm was implanted in a clinical trial.

Exercise 19.2: Clinical Data: Unlocking Insights with Named Entity Recognition

19.4 Science

In many scientific fields, researchers are limited by the quality and resolution of data they can collect. They often must indirectly infer the true parameters of interest using approximate correlations and models built on sparse data points. This constrains the accuracy of scientific understanding and predictions.

The emergence of TinyML opens new possibilities for gathering high-fidelity scientific measurements. With embedded machine learning, tiny, low-cost sensors can automatically process and analyze data locally in real-time. This creates intelligent sensor networks that capture nuanced data at much greater scales and frequencies.

For example, monitoring environmental conditions to model climate change remains challenging due to the need for widespread, continuous data. The Ribbit Project from UC Berkeley is pioneering a crowdsourced TinyML solution (Rao 2021). They developed an open-source CO_2 sensor that uses an onboard microcontroller to process the gas measurements. An extensive dataset can be aggregated by distributing hundreds of these low-cost sensors. The TinyML devices compensate for environmental factors and provide

Rao, Ravi. 2021. "TinyML Unlocks New Possibilities for Sustainable Development Technologies." *Www.wevolver.com*. https://www.wevolver.com/article/tinyml-unlocks-new-possibilities-for-

previously impossible, granular, accurate readings.

sustainable-development-technologies

The potential to massively scale out intelligent sensing via TinyML has profound scientific implications. Higher-resolution data can lead to discoveries and predictive capabilities in fields ranging from ecology to cosmology. Other applications could include seismic sensors for earthquake early warning systems, distributed weather monitors to track microclimate changes, and acoustic sensors to study animal populations.

As sensors and algorithms continue improving, TinyML networks may generate more detailed maps of natural systems than ever before. Democratizing the collection of scientific data can accelerate research and understanding across disciplines. However, it raises new challenges around data quality, privacy, and modeling unknowns. TinyML signifies a growing convergence of AI and the natural sciences to answer fundamental questions.

19.5 Conservation and Environment

TinyML is emerging as a powerful tool for environmental conservation and sustainability efforts. Recent research has highlighted numerous applications of tiny machine learning in domains such as wildlife monitoring, natural resource management, and tracking climate change.

One example is using TinyML for real-time wildlife tracking and protection. Researchers have developed Smart Wildlife Tracker devices that leverage TinyML algorithms to detect poaching activities. The collars contain sensors like cameras, microphones, and GPS to monitor the surrounding environment continuously. Embedded machine learning models analyze the audio and visual data to identify threats like nearby humans or gunshots. Early poaching detection gives wildlife rangers critical information to intervene and take action.

Other projects apply TinyML to study animal behavior through sensors. The smart wildlife collar uses accelerometers and acoustic monitoring to track elephant movements, communication, and moods (Verma 2022). The low-power TinyML collar devices transmit rich data on elephant activities while avoiding burdensome Battery changes. This helps researchers unobtrusively observe elephant populations to inform conservation strategies.

Verma, Team Dual_Boot: Swapnil. 2022. "Elephant AI." *Hackster.io*. https://www.hackster.io/dual_boot/elephant-ai-ba71e9.

super interesting!

On a broader scale, distributed TinyML devices are envisioned to create dense sensor networks for environmental modeling. Hundreds of low-cost air quality monitors could map pollution across cities. Underwater sensors may detect toxins and give early warning of algal blooms. Such applications underscore TinyML's versatility in ecology, climatology, and sustainability.

Researchers from Moulay Ismail University of Meknes in Morocco (Bamoumen et al. 2022) have published a survey on how TinyML can be used to solve environmental issues. However, thoughtfully assessing benefits, risks, and equitable Access will be vital as TinyML expands environmental research and conservation. With ethical consideration of impacts, TinyML offers data-driven solutions to protect biodiversity, natural resources, and our planet.

Bamoumen, Hatim, Anas Temouden, Nabil Benamar, and Yousra Chtouki. 2022. "How TinyML Can Be Leveraged to Solve Environmental Problems: A Survey." In *2022 International Conference on Innovation and Intelligence for Informatics, Computing, and Technologies (3ICT)*, 338–43. IEEE; IEEE. https://doi.org/10.1109/3ict56508.2022.9990661.

19.6 Disaster Response

grammar check

In disaster response, speed and safety are paramount. But rubble and wreckage create hazardous, confined environments that impede human search efforts. TinyML enables nimble drones to assist rescue teams in these dangerous scenarios.

When buildings collapse after earthquakes, small drones can prove invaluable. Equipped with TinyML navigation algorithms, micro-sized drones like the CrazyFlie can traverse cramped voids and map pathways beyond human reach (Bardienus P. Duisterhof et al. 2019). Obstacle avoidance allows the drones to weave through unstable debris. This autonomous mobility lets them rapidly sweep areas humans cannot access. Video 19.1 presents the (Bardienus P. Duisterhof et al. 2019) paper on deep reinforcement learning using drones for source-seeking.

same sentence re-stated 3 times

Duisterhof, Bardienus P, Srivatsan Krishnan, Jonathan J Cruz, Colby R Banbury, William Fu, Aleksandra Faust, Guido CHE de Croon, and Vijay Janapa Reddi. 2019. "Learning to Seek: Autonomous Source Seeking with Deep Reinforcement Learning Onboard a Nano Drone Microcontroller." *ArXiv Preprint* abs/1909.11236. https://arxiv.org/abs/1909.11236.

Video 19.1: Learning to Seek

Crucially, onboard sensors and TinyML processors analyze real-time data to identify signs of survivors. Thermal cameras detect body heat, microphones pick up calls for help, and gas sensors warn of leaks (Bardienus P. Duisterhof et al. 2021). Processing data locally using TinyML allows for quick interpretation to guide rescue efforts. As conditions evolve, the drones can adapt by adjusting their search patterns and priorities. Video 19.2 is an overview of autonomous drones for gas leak detection.

Video 19.2

Additionally, coordinated swarms of drones unlock new capabilities. By collaborating and sharing insights, drone teams comprehensively view the situation. Blanketing disaster sites allows TinyML algorithms to fuse and analyze data from multiple vantage points, amplifying situational awareness beyond individual drones (Bardienus P. Duisterhof et al. 2021).

Duisterhof, Bardienus P., Shushuai Li, Javier Burgues, Vijay Janapa Reddi, and Guido C. H. E. de Croon. 2021. "Sniffy Bug: A Fully Autonomous Swarm of Gas-Seeking Nano Quadcopters in Cluttered Environments." In *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 9099–9106. IEEE; IEEE. https://doi.org/10.1109/iros51168.2021.9636217

Most importantly, initial drone reconnaissance enhances safety for human responders. Keeping rescue teams at a safe distance until drone surveys assess hazards saves lives. Once secured, drones can guide precise personnel placement.

By combining agile mobility, real-time data, and swarm coordination, TinyML-enabled drones promise to transform disaster response. Their versatility, speed, and safety make them a vital asset for rescue efforts in dangerous, inaccessible environments. Integrating autonomous drones with traditional methods can accelerate responses when it matters most.

19.7 Education and Outreach

TinyML holds immense potential to help address challenges in developing regions, but realizing its benefits requires focused education and capacity building. Recognizing this need, academic researchers have spearheaded outreach initiatives to spread TinyML education globally.

In 2020, Harvard University, Columbia University, the International Centre for Theoretical Physics (ICTP), and UNIFEI jointly founded the TinyML for Developing Communities (TinyML4D) network (Zennaro, Plancher, and Reddi 2022). This network empowers universities and researchers in developing countries to harness TinyML for local impact.

Zennaro, Marco, Brian Plancher, and V Janapa Reddi. 2022. "TinyML: Applied AI for Development." In *The UN 7th Multi-Stakeholder Forum on Science, Technology and Innovation for the Sustainable Development Goals*, 2022–05.

A core focus is expanding Access to applied machine learning education. The TinyML4D network provides training, curricula, and lab resources to members. Hands-on workshops and data collection projects give students practical experience. Members can share best practices and build a community through conferences and academic collaborations.

The network prioritizes enabling locally relevant TinyML solutions. Projects address challenges like agriculture, health, and environmental monitoring based on community needs. For example, a member university in Rwanda developed a low-cost flood monitoring system using TinyML and sensors.

TinyML4D includes over 50 member institutions across Africa, Asia, and Latin America. However, greater investments and industry partnerships are needed to reach all underserved regions. The ultimate vision is training new generations to ethically apply TinyML for sustainable development. Outreach efforts today lay the foundation for democratizing transformative technology for the future.

19.8 Accessibility

Accessibility

Technology has immense potential to break down barriers faced by people with disabilities ~~and bridge gaps in accessibility~~. TinyML specifically opens new possibilities for developing intelligent, personalized assistive devices.

With machine learning algorithms running locally on microcontrollers, compact accessibility tools can operate in real time without reliance on connectivity. The National Institute on Deafness and Other Communication Disorders (NIDCD) states that 20% of the world's population has some form of hearing loss. Hearing aids leveraging TinyML could recognize multiple speakers and amplify the voice of a chosen target in crowded rooms. This allows people with hearing impairments to focus on specific conversations.

Similarly, mobility devices could use on-device vision processing to identify obstacles and terrain characteristics. This enables enhanced navigation and safety for the visually impaired. Companies like Envision are developing smart glasses, converting visual information into speech, with embedded TinyML to guide blind people by detecting objects, text, and traffic signals. Video 19.3 below shows the different real-life use cases of the Envision visual aid glasses.

Video 19.3

TinyML could even power responsive prosthetic limbs. By analyzing nerve signals and sensory data like muscle tension, prosthetics and exoskeletons with embedded ML can move and adjust grip dynamically, making control more natural and intuitive. Companies are creating affordable, everyday bionic hands using TinyML. For those with speech difficulties, voice-enabled devices with TinyML can generate personalized vocal outputs from non-verbal inputs. Pairs by Anthropic translates gestures into natural speech tailored for individual users.

By enabling more customizable assistive tech, TinyML makes services more accessible and tailored to individual needs. And through translation and interpretation applications, TinyML can break down communication barriers. Apps like Microsoft Translator offer real-time translation powered by TinyML algorithms.

With its thoughtful and inclusive design, TinyML promises more autonomy and dignity for people with disabilities. However, developers should engage communities directly, avoid compromising privacy, and consider affordability to maximize the benefits. TinyML has huge potential to contribute to a more just, equitable world.

19.9 Infrastructure and Urban Planning

As urban populations swell, cities face immense challenges in efficiently managing resources and infrastructure. TinyML presents a powerful tool for developing intelligent systems to optimize city operations and sustainability. It could revolutionize energy efficiency in smart buildings.

Machine learning models can learn to predict and regulate energy usage based on occupancy patterns. Miniaturized sensors placed throughout buildings can provide granular, real-time data on space utilization, temperature, and more (Seyedzadeh et al. 2018). This visibility allows TinyML systems to minimize waste by optimizing heating, cooling, lighting, etc.

Seyedzadeh, Saleh, Farzad Pour Rahimian, Ivan Glesk, and Marc Roper. 2018. "Machine Learning for Estimation of Building Energy Consumption and Performance: A Review." *Visualization in Engineering* 6 (1): 1–20. https://doi.org/10.1186/s40327-018-0064-7

These examples demonstrate TinyML's huge potential for efficient, sustainable city infrastructure. However, urban planners must consider privacy, security, and accessibility to ensure responsible adoption. With careful implementation, TinyML could profoundly modernize urban life.

19.10 Challenges and Considerations

While TinyML presents immense opportunities, thoughtful consideration of challenges and ethical

While TinyML presents immense opportunities, thoughtful consideration of challenges and ethical implications will be critical as adoption spreads globally. Researchers have highlighted key factors to address, especially when deploying TinyML in developing regions.

A foremost challenge is limited Access to training and hardware (Ooko et al. 2021). Only educational programs exist tailored to TinyML, and emerging economies often need a robust electronics supply chain. Thorough training and partnerships will be needed to nurture expertise and make devices available to underserved communities. Initiatives like the TinyML4D network help provide structured learning pathways.

Ooko, Samson Otieno, Marvin Muyonga Ogore, Jimmy Nsenga, and Marco Zennaro. 2021. "TinyML in Africa: Opportunities and Challenges." In *2021 IEEE Globecom Workshops (GC Wkshps)*, 1–6. IEEE; IEEE. https://doi.org/10.1109/gcwkshps52748.2021.96

Data limitations also pose hurdles. TinyML models require quality localized datasets, which are scarce in under-resourced environments. Creating frameworks to crowdsource data ethically could address this. However, data collection should benefit local communities directly, not just extract value.

Optimizing power usage and connectivity will be vital for sustainability. TinyML's low power needs make it ideal for off-grid use cases. Integrating battery or solar can enable continuous operation. Adapting devices for low-bandwidth transmission where the internet is limited also maximizes impact.

Cultural and language barriers further complicate adoption. User interfaces and devices should account for all literacy levels and avoid excluding subgroups. Voice-controllable solutions in local dialects can enhance accessibility.

Addressing these challenges requires holistic partnerships, funding, and policy support. However, inclusively and ethically scaling TinyML has monumental potential to uplift disadvantaged populations worldwide. With thoughtful implementation, the technology could profoundly democratize opportunity.

19.11 Conclusion

TinyML presents a tremendous opportunity to harness the power of artificial intelligence to advance the UN Sustainable Development Goals and drive social impact globally, as highlighted by examples across sectors like healthcare, agriculture, conservation, and more; embedded machine learning unlocks new capabilities for low-cost, accessible solutions tailored to local contexts. TinyML circumvents barriers like poor infrastructure, limited connectivity, and high costs that often exclude developing communities from emerging technology.

However, realizing TinyML's full potential requires holistic collaboration. Researchers, policymakers, companies, and local stakeholders must collaborate to provide training, establish ethical frameworks, co-design solutions, and adapt them to community needs. Through inclusive development and deployment, TinyML can deliver on its promise to bridge inequities and uplift vulnerable populations without leaving any behind.

If cultivated responsibly, TinyML could democratize opportunity and accelerate progress on global priorities from poverty alleviation to climate resilience. The technology represents a new wave of applied AI to empower societies, promote sustainability, and propel humanity toward greater justice, prosperity, and peace. TinyML provides a glimpse into an AI-enabled future that is accessible to all.

19.12 Resources

Here is a curated list of resources to support students and instructors in their learning and teaching journeys. We are continuously working on expanding this collection and will be adding new exercises soon.

Slides

These slides are a valuable tool for instructors to deliver lectures and for students to review the material at their own pace. We encourage students and instructors to leverage these slides to enhance their understanding and facilitate effective knowledge transfer.

- TinyML for Social Impact.

Videos

- Video 19.1
- Video 19.2
- Video 19.3

Exercises

- Exercise 19.1
- Exercise 19.2

Labs

In addition to exercises, we offer a series of hands-on labs allowing students to gain practical experience with embedded AI technologies. These labs provide step-by-step guidance, enabling students to develop their skills in a structured and supportive environment. We are excited to announce that new labs will be available soon, further enriching the learning experience.

- *Coming soon.*