2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
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Paper ID #37508

Study of Artificial Intelligence Computing Devices for Undergraduate Computer Science and Engineering Labs

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Analysis of Artificial Intelligence Edge Computing Devices for Undergraduate Computer Science and Engineering Labs

Abstract

This work describes and analyzes a set of state-of-the-art artificial intelligence (AI) hardware kits created for education and research that can be used in undergraduate AI labs. AI cloud-based computing devices and solutions like the Arduino-based Tiny Machine Learning kits or the mobile app by Edge Impulse, Raspberry Pi-based AIY Voice kits by Google, Quad-core Arm Cortex-A53 and Cortex-M4F-based Google Coral Dev Boards, as well as the more powerful Jetson AGX Xavier (512-core NVIDIA Ampere architecture GPU), and Jetson AGX Orin (2048-core NVIDIA Ampere architecture GPU) Developer kits, are compared using published characteristics and direct experiments. The comparison criteria used are (1) ease of setup and first use, (2) learning curve and required prior knowledge, (3) learning community support availability, (4) suitability for undergraduate learning, (5) computational speed, and (6) cost including both the hardware cost and the subscription services cost. Based on the results of the analysis the tested AI computing devices are ranked for use in various levels of undergraduate curricula. The goal is to provide the faculty interested in developing their own AI labs with some guidance in choosing appropriate AI hardware from an experimental perspective.

1. Introduction

With rapid advancements in artificial intelligence (AI), AI applications are becoming ubiquitous throughout the world. Many businesses and even entire countries are placing AI developments high on their lists of strategic goals and initiatives. Such large endeavors require armies of well-trained and knowledgeable scientists, programmers, and engineers often drawn from undergraduate computer science and engineering programs. Many widely used AI applications rely on commercially available mass-produced computing devices and cloud computing resources. However, these AI computing devices are often not designed for teaching AI concepts, algorithms, and/or practice.

In addition, in recent years, the proliferation of AI applications in automation in general and Industry 4.0 in particular has placed a greater demand on the computational needs of Internet of Things (IoT) edge-computing devices. Real-time AI-based control decisions often need to be made within a few milliseconds which is not attainable when using the cloud computing paradigm. Instead, edge computing, which occurs physically close to the sensors and actuators, is implemented. Thus, it is important for engineering students to gain hands-on experience with edge computing devices capable of performing AI tasks.

What follows are sections on Previous Work justifying experiential learning in general, then, Description of AI Development Kits, Comparative Analysis, and Summary and Conclusions.

2. Previous Work

This section provides a short review of education literature related to the developments of an experientially-based educational continuum as well as the AI in edge computing. Over 80 years ago, Dewey [1] recognized that practical laboratory experiences and projects are important parts of learning. Later, Kolb, in his Experiential Learning Cycle (KLC) [2], placed large importance on experiencing and applying/doing as essential elements of optimal learning. Positive experiential learning from accomplishing successful projects is also emphasized as an important component of increasing self-efficacy [3]. Therefore, it is not surprising that KLC implementations were reported in most of the engineering disciplines like civil engineering [4] – [6], mechanical engineering [6], chemical engineering [4], [5], [7], aeronautical engineering [6], industrial engineering [8], and manufacturing engineering [4], [5], [9]. Bansal and Kumar [10] describe a state-of-the-art IoT ecosystem that includes edge devices and uses cloud and fog computing. McConnell *et al.* [11] address an introductory course on designing edge computing devices within the IoT frame, while Warden and Situnayake [12] describe detailed implementations of the TensorFlow Lite library within the TinyML environment for AI applications of low-power microcontrollers like Arduino Nano 33 BLE Sense.

This work involves a range of edge devices, from low-power (a few mW for TinyML kit) to high-power devices (30 W for Jetson AGX Orin) of various capabilities.

3. Description of AI Development Kits

This section describes seven AI hardware kits that can be used to learn how to implement available AI applications in edge devices for educational and demonstration purposes. The following devices are described: Arduino-based Tiny Machine Learning Kits or the mobile apps by Edge Impulse, Raspberry Pi-based AIY Voice Kits by Google, Quad-core Arm Cortex-A53 and Cortex-M4F-based Google Coral Dev Boards, as well as more powerful NVIDIA's Jetson AGX Xavier (512-core NVIDIA Ampere architecture GPU), and Jetson AGX Orin (2048-core NVIDIA Ampere architecture GPU) Developer Kits.

3.1 Tiny Machine Learning Kit Supported by Edge Impulse ML Development Suite

The Tiny Machine Learning (TinyML) Kit hardware consists of four parts: (1) an Arduino Nano 33 BLE Sense, (2) a Tiny Machine Learning Shield, (3) an OV7675 camera module (VGA 640x480, 0.3 Mega Pixels lens, 1 or 5 fps), and (4) a USB cable (type-A to micro-B). The Arduino Nano 33 BLE Sense includes a Nordic Semiconductor nRF52840 microcontroller (64 MHz, 1MB flash, 256K SRAM), a 9-axis LSM9DS1 Inertial Measurement Unit (IMU), a microphone, a pressure sensor, a gesture sensor, a proximity sensor, a light color sensor, a light intensity sensor, BLE and Bluetooth 5 connectivity, headers, and one micro-USB connector. However, the kit does not include an advertised HTS221 onboard temperature and humidity sensor due to supply chain problems in obtaining these sensors. The four parts of the kit are very easy to assemble. An assembled kit is depicted in Figure 1. TinyML is one of the devices supported by the Edge Impulse development ML suite that uses TensorFlow Lite and various pre-trained models for AI applications that can be deployed through mobile or other embedded applications.

Edge Impulse provides up to ten kits free through their University Program. Otherwise, kits can be purchased at about $60 per kit.

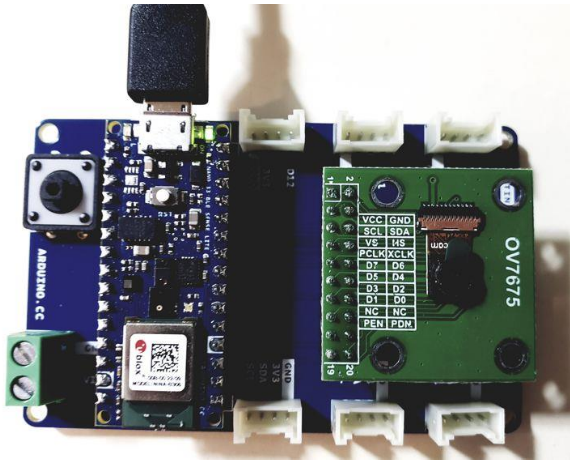

Figure 1. Assembled Tiny Machine Learning Kit

The software installation is fairly easy since it is performed from the Arduino Integrated Development Environment (IDE). Various sensor libraries, as well as the TinyML library are installed with the Arduino IDE. The TinyML installation includes TensorFlow Lite and an OmniVision OV7675 camera library. Example programs are provided for testing sensors like IMU, microphone, and camera, as well as gesture recognition, speech recognition, and person detection. Even the *Hello World* program is capable of recognizing words like “yes” and “no” and can turn an RGB LED to green for “yes,” red for “no,” or blue for any other word. While the kit is not suited for training of neural networks (NNs), it is appropriate for inference.

3.2 Mobile App by Edge Impulse Supported by Edge Impulse ML Development Suite

Smartphones are more powerful computing devices than the TinyML kits, thus, they can be used as edge computing devices as well. A smartphone has a camera, a microphone, and often an IMU. Edge Impulse uses TensorFlow Lite and various pre-trained models for smartphone AI applications. To use the Edge Impulse services one needs to create an account. After logging in, a smartphone is used to collect data, set training settings for an NN, select NN architecture, choose a model, train the network, provide training performance metrics like accuracy and loss function, provide a confusion matrix, show spectral features, and show on-device performance. However, unlike the TinyML kit, smartphones don’t have input/output pins to receive inputs from other sensors or to directly control outside devices.

3.3 *AIY Voice Kit V2 Supported by the Google Assistant or Cloud Speech-to-Text Service*

This cardboard cube kit from Google is based on a Raspberry Pi Zero WH single-board computer (SBC) with Wi-Fi and Bluetooth on-board connectivity. The kit shown in Figure 2 also includes a voice bonnet, a speaker, a single large push button, a cardboard box, and a Micro USB cable. Since the Raspberry Pi is a SBC it is somewhat harder to setup than the TinyML kit. One of the kit’s characteristics is that it acts similarly to voice-controlled virtual assistants like Amazon Alexa, except that there is a large button on top of the device that needs to be pressed to get the assistant’s attention. The kit is a natural language processor connected to the Google Assistant or Cloud Speech-to-Text service (a free 60 min/month service).

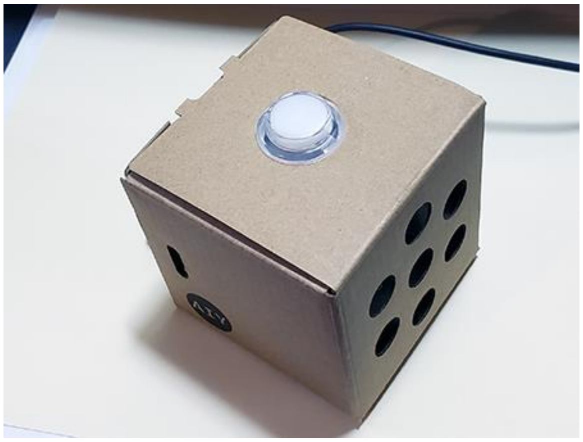

Figure 2. AIY Voice Kit V2 from Google

3.4 Coral Dev Board by Google

The Coral Dev Board with a camera and a cooling fan shown in Figure 3 is a powerful SBC with an on-board Google Edge TPU (Tensor Processing Unit) ML accelerator coprocessor capable of running 4 TOPS (Tera operations per second) using 2W of power. This multiprocessor system includes a quad-core Arm Cortex-A53 and a Cortex-M4F-based processor. Furthermore, the Coral Dev Board uses TensorFlow Lite and Mendel Linux (a derivative of Debian). As an edge device, it uses a considerable amount of power, so it is not suitable for long-term AI applications that require batteries.

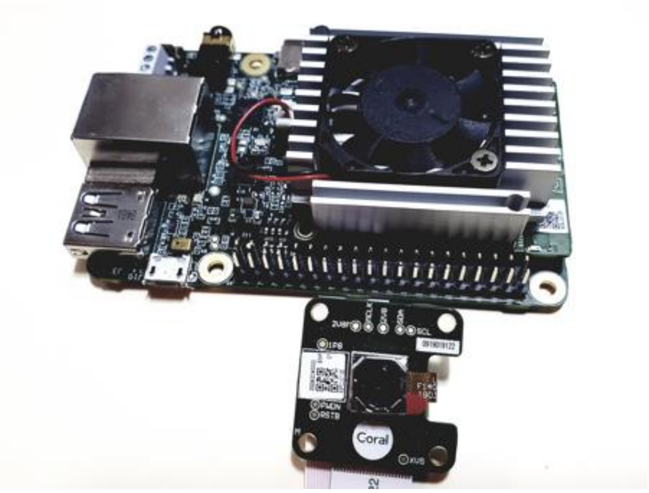

Figure 3. Coral Dev Board with a Camera

3.5 Jetson AGX Xavier Developer Kit

The Jetson AGX Xavier Developer Kit depicted in Figure 4 is a powerful SBC with a Graphical Processing Unit (GPU) capable of delivering 32 TOPS and having 512 NVIDIA CUDA cores and 64 Tensor cores. The system is designed for use in robotics and autonomous vehicles where high energy consumption is not a major concern. It weighs 800 g without the power supply. In addition, it can consume up to 30W, and it does not work out-of-the-box. It requires another computer to flash its operating system. It runs an Ubuntu flavor of Linux.

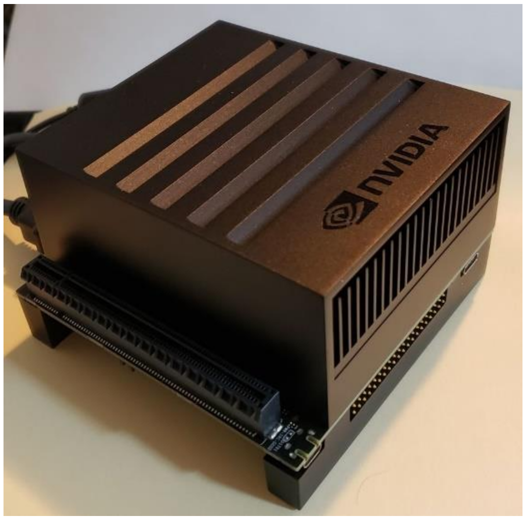

Figure 4. Jetson AGX Xavier Developer Kit by NVIDIA

3.6 Jetson AGX Orin Developer Kit

The Jetson AGX Orin Developer Kit from NVIDIA shown in Figure 5 is a professional developer-grade SBC capable of executing 275 TOPS and having a GPU with 2048 NVIDIA cores and 64 Tensor cores. The system weighs 1 kg without the power supply and may consume up to 50W. Ubuntu Linux is preinstalled so the kit can be connected to a monitor, keyboard, and a mouse and be ready to run in a couple of minutes. The Orin kit can be viewed as an easier to use and much faster version of the Xavier kit.

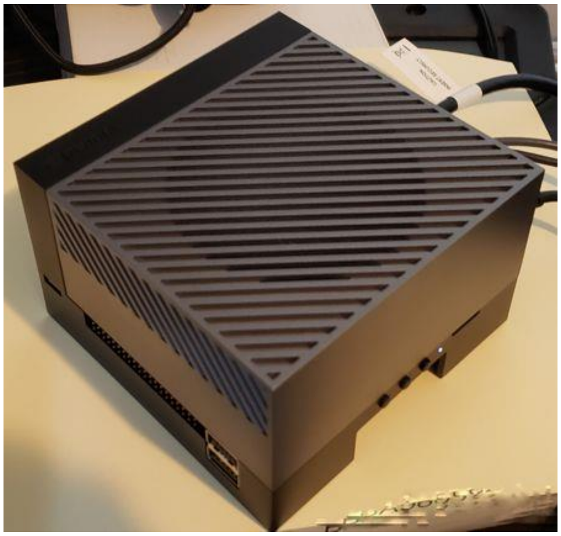

Figure 5. Jetson AGX Orin Developer Kit by NVIDIA

4. Comparative Analysis

Table 1 compares a number of currently available AI hardware kits. The comparison criteria used are (1) ease of setup and first use, (2) learning curve and required prior knowledge, (3) learning community support availability, (4) suitability for undergraduate learning, (5) computational speed, and (6) cost including both the hardware cost and the subscription services cost.

Table 1. Comparative Analysis of AI Hardware Kits

Comparison Criteria	**TinyML Arduino**	**TinyML Mobile App**	**AIY Voice V2**	**Coral Dev Board**	**Jetson AGX Xavier**	**Jetson AGX Orin**
Ease of Setup	Easy	Easy	Easy	Medium	Hard	Medium
Learning Curve	Flat	Flat	Moderate	Moderate	Steep	Moderate
Community Support	Adequate	Good	Discontinued	Good	Good	Good
Suitability for Undergraduate Learning – Ranking (1 high)	2	1	3	5	6	4
Computational speed	Low	Medium	Medium	Medium	High	Very High
Cost ($)	60	0	30	150	800	2000

To motivate the first-year undergraduate students to learn AI, the TinyML mobile app can be used as an exemplar of AI processes, from data acquisition to inference. Such a lab exercise could be performed in a single lab session. Then, as students learn and use Arduino microcontrollers, the TinyML Kit could be used again. With good instructions, a single 2-hour lab session could be adequate for an introduction to TinyML and machine learning in general. AIY Voice kit requires some assembly, and has a SBC. It connects to the cloud and it requires some knowledge of Raspbian Linux, thus it may be better suitable for third and fourth-year students. In addition, some experience with Python becomes necessary. Coral Dev Board is a more expensive and more powerful edge computing device that may have power requirements unsuitable for many AI edge computing applications. However, the increase in computer speed may be required for use in some student research/design projects dealing with automation and industrial settings. Finally, the NVIDIA Jetson development kits are both powerful edge devices designed for AI applications in robotics, automation, and autonomous vehicles. With inputs from up to 6 cameras, the kits are suitable for AI applications for larger systems and research projects for upperclassman or graduate students.

Due to the recent increase in interest related to AI applications, the authors are planning to investigate students' acceptance of AI tools like the TinyML kit and the TinyML mobile app.

5. Summary and Conclusions

In this work, a comparative analysis of various AI devices was conducted with respect to their suitability for undergraduate engineering education. Based on the defined criteria, the results show that there were considerable differences between devices. Namely, the Arduino nano 33 BLE Sense-based TinyML kit and the mobile app by Edge Impulse are well suited for students in their first or second year of study. AIY Voice kits do require some knowledge of Raspbian Linux which makes them suitable for students who are somewhat familiar with Linux and Python. Coral Dev Boards, as well as the Jetson AGX Xavier and Jetson AGX Orin Developer Kits are more suitable for special design/research projects at the senior or graduate levels.

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