REAL-TIME OBJECT DETECTION WITH TENSORFLOW MODEL USING EDGE COMPUTING ARCHITECTURE

A FINAL YEAR PROJECT REPORT (EEXXXX)

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BONAFIDE CERTIFICATE

Certified that this design project report titled "**REAL-TIME OBJECT DETECTION WITH TENSORFLOW MODEL USING EDGE COMPUTING ARCHITECTURE**" is the bonafide work of ALLA ESWARA RAO, M. PAVAN KALYAN, who carried out the design project work under my supervision. Certified further that to the best of my knowledge the work reported here does not form part of any other design project on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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The design Project Viva-Voce Examination is held on …………….

INTERNAL EXAMINER	**EXTERNAL EXAMINER**

ABSTRACT

This paper presents the capturing of objects using Wi-Fi enabled modular esp32 camera and processes the captured steam of data using machine learning and computer vision techniques, then sends the processed data to the cloud, there are major cloud providers in the market who occupied more than 80% of the global public market the cloud providers are Google Cloud, Amazon AWS, Microsoft Azure. Google Cloud Platform (GCP) is been our primary choice because of its good documentation availability, The Cloud IoT-Core Gateway, as well as a serverless cloud layer to store all of the data. The cloud functions help to trigger the notifications to the users when the cameras detect what we have trained the model. The Edge computing project uses an ESP32 With cameras as a device listener and a raspberry pi as an edge server which has an image classifier model trained with TensorFlow

ACKNOWLEDGEMENT

First and foremost we would like to thank the Lord Almighty for his presence and immense blessings throughout the design project work.

It's a matter of pride and privilege for us to express our deep gratitude to the management of HITS for providing us the necessary facilities and support.

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CHAPTER 1

INTRODUCTION, SCOPE & OBJECTIVES OF THE INVESTIGATION

1.1 INTRODUCTION

Edge computing is a framework of a distributed computing that brings industrial grade applications closer to the data generating source like local edge servers. [1] This close contact to data at its source can have significant business advantages. We shifted from using on-premises servers to remote servers, which offers scalability, reduction of maintenance cost, and an easy usage environment. But for some cases, we need to still cope with processing the data close to where the data is generated. It will provide faster insights, better response and great bandwidth availability All around us from our smart watch to the safety monitoring in the industries and manufacturing sectors edge computing is already in use, in manufacturing sectors to monitor manufacturing processes and apply machine learning techniques and real-time analytics to detect the production errors. A Tesla car can process sensor data that allows it to recognize and self-pilot around pedestrians, other cars on the road with this computer capability at the edge. [3] [10] Preloaded mapping data and GPS connectivity are also used to process the sensor data. The edge computing applications are endless. And also, there are several reasons to use edge computing when response time and system availability are critical, even when the internet is unavailable when to use less network bandwidth, privacy, and the considerable part when the processing in the cloud becomes too expensive. The project aims to fetch a live stream of video from cameras and a on-premises server that searches for cameras using mDNS and uses machine learning [2] [11] and computer vision techniques to analyze the collected stream before uploading it to the Google cloud platform, which will give the ability to stream the footage anywhere anytime and the trigger functions helps triggers alert to the local police station when a person appears with a gun in-store or receive an alert when an unauthorized person tries to enter a home [4] [12], it gives the ability to train custom model and incorporate to the edge computing architecture, the possibilities are endless and up to the end-user creativity and use case of their requirement.

1.1.1 WHAT IS EDGE COMPUTING?

Edge computing is a distributed information technology (IT) architecture in which client data computing that's done at or near the source of the data

"A common misconception is that edge and IoT are synonymous. Edge computing is a topology- and location-sensitive form of distributed computing, while IoT is a use case instantiation of edge computing." The term refers to architecture rather than a specific technology.

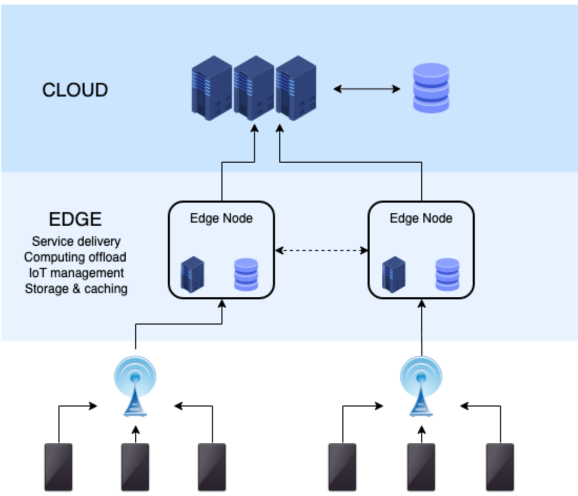
The origins of edge computing lie in content distribution networks that were created in the late 1990s to serve web and video content from edge servers that were deployed close to users. In the early 2000s, these networks evolved to host applications and application components at the edge servers, resulting in the first commercial edge computing services that hosted applications such as dealer locators, shopping carts, real-time data aggregators, and ad insertion engines.

One definition of edge computing is any type of computer program that delivers low latency nearer to the requests. Karim Arabi, in an IEEE DAC 2014 Keynote and subsequently in an invited talk at MIT's MTL Seminar in 2015, defined edge computing broadly as all computing outside the cloud happening at the edge of the network, and more specifically in applications where real-time processing of data is required. In his definition, cloud computing operates on big data while edge computing operates on "instant data" which is real-time data generated by sensors or users.

The term is often used synonymously with fog computing.

According to *The State of the Edge* report, edge computing concentrates on servers "in proximity to the last mile network." Alex Reznik, Chair of the ETSI MEC ISG standards committee loosely defines the term: "anything that's not a traditional data center could be the 'edge' to somebody."

Edge nodes used for game streaming are known as *gamelets*, which are usually one or two hops away from the client. Per Anand and Edwin say "the edge node is mostly one or two hops away from the mobile client to meet the response time constraints for real-time games' in the cloud gaming



Edge computing may employ virtualization technology to make it easier to deploy and run a wide range of applications on edge servers.

Privacy and security

The distributed nature of this paradigm introduces a shift in security schemes used in cloud computing. In edge computing, data may travel between different distributed nodes connected through the Internet and thus requires special encryption mechanisms independent of the cloud. Edge nodes may also be resource-constrained devices, limiting the choice in terms of security methods. Moreover, a shift from centralized top-down infrastructure to a decentralized trust model is required. On the other hand, by keeping and processing data at the edge, it is possible to increase privacy by minimizing the transmission of sensitive information to the cloud. Furthermore, the ownership of collected data shifts from service providers to end-users.

Scalability

Scalability in a distributed network must face different issues. First, it must take into account the heterogeneity of the devices, having different performance and energy constraints, the highly dynamic condition, and the reliability of the connections compared to more robust infrastructure of cloud data centers. Moreover, security requirements may introduce further latency in the communication between nodes, which may slow down the scaling process.

Reliability

Management of failovers is crucial in order to keep a service alive. If a single node goes down and is unreachable, users should still be able to access a service without interruptions. Moreover, edge computing systems must provide actions to recover from a failure and alerting the user about the incident. To this aim, each device must maintain the network topology of the entire distributed system, so that detection of errors and recovery become easily applicable. Other factors that may influence this aspect are the connection technologies in use, which may provide different levels of reliability, and the accuracy of the data produced at the edge that could be unreliable due to particular environment conditions. As an example an edge computing device, such as a voice assistant may continue to provide service to local users even during cloud service or internet outages.

Speed

Edge computing brings analytical computational resources close to the end users and therefore can increase the responsiveness and throughput of applications. A well-designed edge platform would significantly outperform a traditional cloud-based system. Some applications rely on short response times, making edge computing a significantly more feasible option than cloud computing. Examples range from IoT to autonomous driving, anything health or human / public safety relevant, or involving human perception such as facial recognition, which typically takes a human between 370-620 ms to perform. Edge computing is more likely to be able to mimic the same perception speed as humans, which is useful in applications such as augmented reality where the headset should preferably recognize who a person is at the same time as the wearer does.

Efficiency

Due to the nearness of the analytical resources to the end users, sophisticated analytical tools and Artificial Intelligence tools can run on the edge of the system. This placement at the edge helps to increase operational efficiency and is responsible for many advantages to the system.

Additionally, the usage of edge computing as an intermediate stage between client devices and the wider internet results in efficiency savings that can be demonstrated in the following example: A client device requires computationally intensive processing on video files to be performed on external servers. By using servers located on a local edge network to perform those computations, the video files only need to be transmitted in the local network. Avoiding transmission over the internet results in significant bandwidth savings and therefore increases efficiency. Another example is voice recognition. If the recognition is performed locally, it is possible to send the recognized text to the cloud rather than audio recordings, significantly reducing the amount of required bandwidth.

Applications

Edge application services reduce the volumes of data that must be moved, the consequent traffic, and the distance that data must travel. That provides lower latency and reduces transmission costs. Computation offloading for real-time applications, such as facial recognition algorithms, showed considerable improvements in response times, as demonstrated in early research. Further research showed that using resource-rich machines called cloudlets near mobile users, which offer services typically found in the cloud, provided improvements in execution time when some of the tasks are offloaded to the edge node. On the other hand, offloading every task may result in a slowdown due to transfer times between device and nodes, so depending on the workload, an optimal configuration can be defined.

Another use of the architecture is cloud gaming, where some aspects of a game could run in the cloud, while the rendered video is transferred to lightweight clients running on devices such as mobile phones, VR glasses, etc. This type of streaming is also known as *pixel streaming*.

Other notable applications include connected cars, autonomous cars, smart cities, Industry 4.0 (smart industry), and home automation systems.

1.1.2 Raspberry Pi?

Raspberry Pi () is a series of small single-board computers (SBCs) developed in the United Kingdom by the Raspberry Pi Foundation in association with Broadcom. The Raspberry Pi project originally leaned towards the promotion of teaching basic computer science in schools and in developing countries. The original model became more popular than anticipated, selling outside its target market for uses such as robotics. It is widely used in many areas, such as for weather monitoring, because of its low cost, modularity, and open design. It is typically used by computer and electronic hobbyists, due to its adoption of HDMI and USB devices.

After the release of the second board type, the Raspberry Pi Foundation set up a new entity, named Raspberry Pi Trading, and installed Eben Upton as CEO, with the responsibility of developing technology. The Foundation was rededicated as an educational charity for promoting the teaching of basic computer science in schools and developing countries. Most Pis are made in a Sony factory in Pencoed, Wales, while others are made in China and Japan.

Series and generations

There are three series of Raspberry Pi, and several generations of each have been released. Raspberry Pi SBCs feature a Broadcom system on a chip (SoC) with an integrated ARM-compatible central processing unit (CPU) and on-chip graphics processing unit (GPU), while Raspberry Pi Pico has an RP2040 system on chip with an integrated ARM-compatible central processing unit (CPU).

Raspberry Pi

- The first generation (**Raspberry Pi Model B**) was released in February 2012, followed by the simpler and cheaper **Model A**.
- **Raspberry Pi 3 Model B** was released in February 2016 with a 1.2 GHz 64-bit quad core ARM Cortex-A53 processor, on-board 802.11n Wi-Fi, Bluetooth and USB boot capabilities.
- On Pi Day 2018, the **Raspberry Pi 3 Model B+** was launched with a faster 1.4 GHz processor, a three-times faster gigabit Ethernet (throughput limited to ca. 300 Mbit/s by the internal USB 2.0 connection), and 2.4 / 5 GHz dual-band 802.11ac Wi-Fi (100 Mbit/s). Other features are Power over Ethernet (PoE) (with the add-on PoE HAT), USB boot and network boot (an SD card is no longer required).
- **Raspberry Pi 4 Model B** was released in June 2019 with a 1.5 GHz 64-bit quad core ARM Cortex-A72 processor, on-board 802.11ac Wi-Fi, Bluetooth 5, full gigabit Ethernet (throughput not limited), two USB 2.0 ports, two USB 3.0 ports, 2-8 GB of RAM, and dual-monitor support via a pair of micro HDMI (HDMI Type D) ports for up to 4K resolution. The version with 1 GB RAM has been abandoned and the prices of the 2 GB version have been reduced. The 8 GB version has a revised circuit board. The Pi 4 is also powered via a USB-C port, enabling additional power to be provided to downstream peripherals, when used with an appropriate PSU. But the Pi can only be operated with 5 volts and not 9 or 12 volts like other mini computers of this class. The initial Raspberry Pi 4 board has a design flaw where third-party e-marked USB cables, such as those used on Apple MacBooks, incorrectly identify it and refuse to provide power. Tom's Hardware tested 14 different cables and found that 11 of them turned on and powered the Pi without issue. The design flaw was fixed in revision 1.2 of the board, released in late 2019. In mid-2021, Pi 4 B models appeared with the improved Broadcom BCM2711**C0**. The manufacturer is now using this chip for the Pi 4 B and Pi 400. However, the tack frequency of the Pi 4 B was not increased in the factory.

- **Raspberry Pi 400** was released in November 2020. It features a custom board that is derived from the existing Raspberry Pi 4, specifically remodeled with a keyboard attached. The case was derived from that of the Raspberry Pi Keyboard.

A robust cooling solution (i.e. a broad metal plate) and an upgraded switched-mode power supply allow the Raspberry Pi 400's Broadcom BCM2711C0 processor to be clocked at 1.8 GHz, which is slightly higher than the Raspberry Pi 4 it's based on. The keyboard-computer features 4 GB of LPDDR4 RAM.

Model Comparison Table

Family	Model	SoC	Memory	Form Factor	Ethernet	Wireless	GPIO	Released	Discontinued
Raspberry Pi	B	BCM2835	256 MB	Standard	Yes	No	26-pin	Feb-12	Yes
			512 MB					Oct-12	
	A		256 MB		No			2013	No
	B+		512 MB		Yes		40-pin	2014	
	A+			Compact	No				
Raspberry Pi 2	B	BCM2836/7	1 GB	Standard	Yes	No		2015	
Raspberry Pi Zero	Zero	BCM2835	512 MB	Ultra-Compact	No	No			
	W/ WH					Yes		2017	
	2 W	BCM2710 A1, custom Raspberry Pi system-in-package RP3A0						2021	
Raspberry Pi 3	B	BCM2837 A0/B0	1 GB	Standard	Yes			2016	
	A+	BCM2837 B0	512 MB	Compact	No	Yes (dual band)		2018	
	B+		1 GB	Standard	Yes (Gigabit Ethernet)			2018	
Raspberry	B	BCM2711	1 GB	Standard	Yes (Giga	Yes (dual		2019	March 2020 to

Pi 4					bit Ethernet)	band)			October 2021
			2 GB						
			4 GB						
			8 GB						
	400		4 GB	Keyboard				2020	No
Raspberry Pi Pico	N/A	RP2040	264 KB	Pico (21 mm × 51 mm)	No	No	26-pin	2021	

ESP32 is a series of the low-cost, low-power system on a chip microcontrollers with integrated Wi-Fi and dual-mode Bluetooth. The ESP32 series employs either a Tensilica Xtensa LX6 microprocessor in both dual-core and single-core variations, Xtensa LX7 dual-core microprocessor or a single-core RISC-V microprocessor and includes built-in antenna switches, RF balun, power amplifier, low-noise receive amplifier, filters, and power management modules. ESP32 is created and developed by Espressif Systems, a Shanghai-based Chinese company, and is manufactured by TSMC using their 40 nm process. It is a successor to the ESP8266 microcontroller.

Features

Features of the ESP32 include the following:

- Processors:
    - CPU: Xtensa dual-core (or single-core) 32-bit LX6 microprocessor, operating at 160 or 240 MHz and performing at up to 600 DMIPS
    - Ultra low power (ULP) co-processor
- Memory: 320 KiB RAM, 448 KiB ROM
- Wireless connectivity:
    - Wi-Fi: 802.11 b/g/n
    - Bluetooth: v4.2 BR/EDR and BLE (shares the radio with Wi-Fi)
- Peripheral interfaces:
    - 34 × programmable GPIOs
    - 12-bit SAR ADC up to 18 channels
    - 2 × 8-bit DACs
    - 10 × touch sensors (capacitive sensing GPIOs)
    - 4 × SPI
    - 2 × I²S interfaces
    - 2 × I²C interfaces
    - 3 × UART
    - SD/SDIO/CE-ATA/MMC/eMMC host controller
    - SDIO/SPI slave controller

    - Ethernet MAC interface with dedicated DMA and planned IEEE 1588 Precision Time Protocol support
    - CAN bus 2.0
    - Infrared remote controller (TX/RX, up to 8 channels)
    - Motor PWM
    - LED PWM (up to 16 channels)
    - Hall effect sensor
    - Ultra low power analog pre-amplifier
- Security:
    - IEEE 802.11 standard security features all supported, including WPA, WPA2, WPA3 (depending on version) and WAPI
    - Secure boot
    - Flash encryption
    - 1024-bit OTP, up to 768-bit for customers
    - Cryptographic hardware acceleration: AES, SHA-2, RSA, elliptic curve cryptography (ECC), random number generator (RNG)
- Power management:
    - Internal low-dropout regulator
    - Individual power domain for RTC
    - 5 µA deep sleep current
    - Wake up from GPIO interrupt, timer, ADC measurements, capacitive touch sensor interrupt

PlatformIO is a set of cross-platform tools for developing for embedded devices. It supports a lot of different platforms and frameworks for IoT development and also a huge set of libraries made by the community that can be easily used on your project.

1.4 Applications

This edge computing architecture has endless applications we can use this as we configured, we can add our custom model to this architecture to our specific need. One of the applications of this project is to detect when an unauthorized person appears with a gun or knife in a supermarket or malls It automatically triggers a notification to the authorities.

What is Object detection?

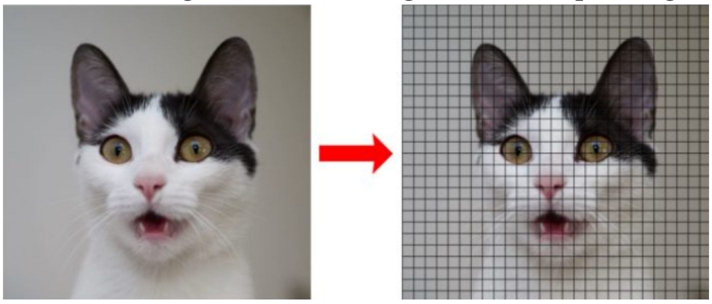
Object detection is a computer vision technique in which a software system can detect, locate, and trace the object from a given image or video. The special attribute of object detection is that it identifies the class of objects (person, table, chair, etc.) and their location-specific coordinates in the given image. The location is pointed out by drawing a bounding box around the object. The bounding box may or may not accurately locate the position of the object. The ability to locate the object inside an image defines the performance of the algorithm used for detection. Face detection is one of the example of object detection.

These object detection algorithms might be pre-trained or can be trained from scratch. In most use cases, we use pre-trained weights from pre-trained models and then fine-tune them as per our requirements and different use cases.

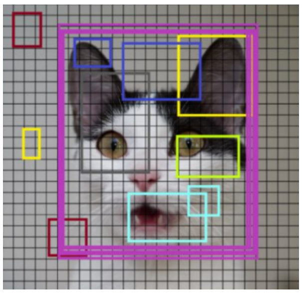
How does Object detection work?

Generally, the object detection task is carried out in three steps:

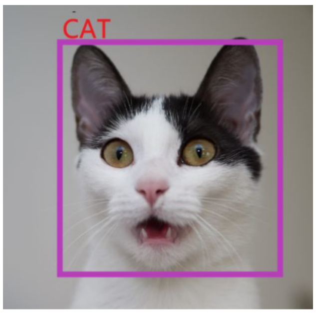
- Generates the small segments in the input as shown in the image below. As you can see the large set of bounding boxes are spanning the full image



- Feature extraction is carried out for each segmented rectangular area to predict whether the rectangle contains a valid object



- Overlapping boxes are combined into a single bounding rectangle (Non-Maximum Suppression)



What is TensorFlow?

Tensorflow is an open-source library for numerical computation and large-scale machine learning that ease Google Brain TensorFlow, the process of acquiring data, training models, serving predictions, and refining future results.

- Tensorflow bundles together Machine Learning and Deep Learning models and algorithms.
- It uses Python as a convenient front-end and runs it efficiently in optimized C++.
- Tensorflow allows developers to create a graph of computations to perform.
- Each node in the graph represents a mathematical operation and each connection represents data. Hence, instead of dealing with low-details like figuring out proper ways to hitch the output of one function to the input of another, the developer can focus on the overall logic of the application.

In the deep learning artificial intelligence research team at Google, Google Brain, in the year 2015 developed TensorFlow for Google's internal use. This Open-Source Software library is used by the research team to perform several important tasks.

TensorFlow is at present the most popular software library. There are several real-world applications of deep learning that makes TensorFlow popular. Being an Open-Source library for deep learning and machine learning, TensorFlow finds a role to play in text-based applications, image recognition, voice search, and many more. DeepFace, Facebook's image recognition system, uses TensorFlow for image recognition. It is used by Apple's Siri for voice recognition. Every Google app that you use has made good use of TensorFlow to make your experience better.

What is TensorFlow object detection API?

The TensorFlow Object Detection API is an open-source framework built on top of TensorFlow that makes it easy to construct, train and deploy object detection models.

- There are already pre-trained models in their framework which are referred to as Model Zoo.
- It includes a collection of pre-trained models trained on various datasets such as the
    - COCO (Common Objects in Context) dataset,
    - the KITTI dataset,
    - and the Open Images Dataset.

Object Detection Using TensorFlow

As mentioned above the knowledge of neural networks and machine learning is not mandatory for using this API as we are mostly going to use the files provided in the API. All we need is some knowledge of python and a passion for completing this project. Also, I assume Anaconda is already installed on your PC.So let us start by downloading some files:

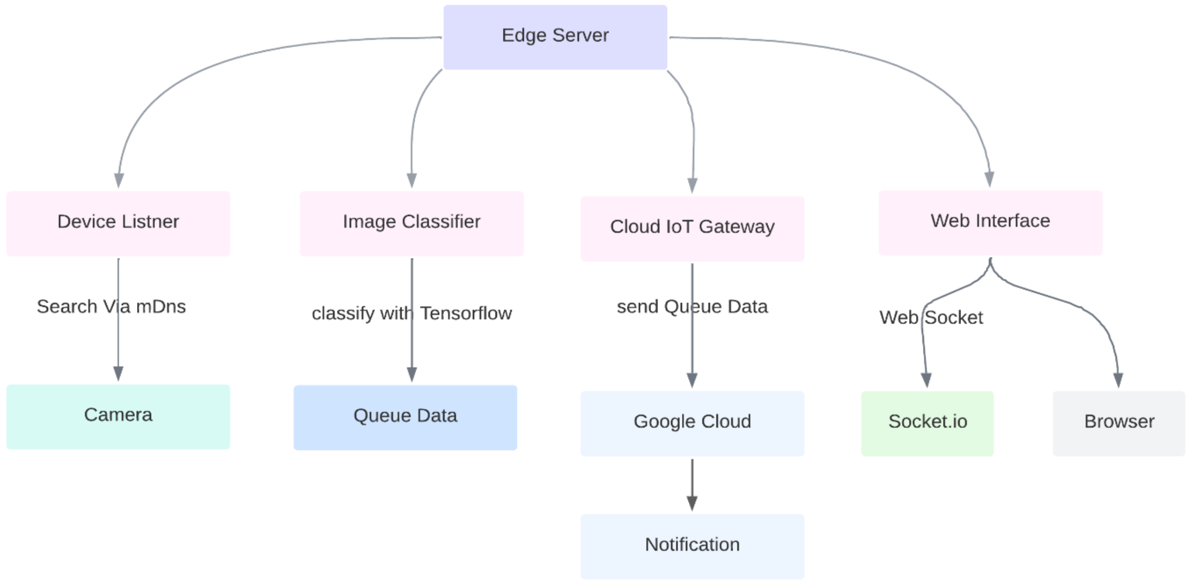
TensorFlow architecture overview

The object detection application uses the following components:

- TensorFlow. An open source machine learning library developed by researchers and engineers within Google's Machine Intelligence research organization. TensorFlow runs on multiple computers to distribute the training workloads.
- Object Detection API. An open source framework built on top of TensorFlow that makes it easy to construct, train, and deploy object detection models.
- Pre-trained object detection models. The Object Detection API provides pre-trained object detection models for users running inference jobs. Users are not required to train models from scratch.

Methodology

- At an edge computing layer, the processing happens on edge servers which are directly interfaced with a couple to a few thousand and even millions of sensors and controllers, these servers are capable of performing analytics and running machine learning models to make decisions in real-time. [5] In this project, as a Wi-Fi camera, we're using an ESP32 module with an integrated camera. The processed stream data is securely transferred to Google Cloud Platform utilizing Cloud IoT core using a Raspberry Pi 4B board acts as a edge server running the TensorFlow object detection model. [6] The data is processed in an event-based way and triggers alerts and a local server provides access to the local web interface to monitor cameras offline, while firebase cloud functions archive the data on firebase to steam the video to internet-connected users on the web interface. The Architecture has two sides Local server-side and Online server-side, local server-side we have cameras as sensors and a local server gateway (raspberry pi), and on the other side, we designed the data flow on a google cloud platform.



Litreature survey

Marieh Talebkhah; Aduwati Sali; Mohen Marjani; Meisam Gordan; Shaiful Jahari Hashim; Fakhrul Zaman Rokhani "Edge computing: Architecture, Applications and Future Perspectives " 2020 IEEE 2nd International Conference on Artificial Intelligence in Engineering and Technology (IICAIET)

- This paper Explains the importance of edge device of the network to centralized cloud computing

  and Various edge computing techniques.

Kristian Dokic "Microcontrollers on the Edge – Is ESP32 with Camera Ready for Machine Learning?" Polytechnic in Pozega, 34000 Pozega, Croatia

- In this paper well-known SoC ESP32 has been analyzed. this paper will analyze the possibility of using

  ESP32 with a built-in camera for machine learning algorithms. Focus of research will be on durations

  of photographing and photograph processing, because that can be a bottleneck of a machine learning

  tasks.

Proposed method

At an edge computing layer, the processing happens on edge servers which are directly interface with couple to few thousand and even millions of sensors and controllers, these servers are capable of perform analytics and run machine learning models to make decisions real-time. In this project we are using ESP32 module with an integrated camera as a Wi-Fi camera. A Raspberry pi board as a local server which runs TensorFlow object detection model, the data is sent to google cloud platform securely using Cloud IoT core. The data is processed in event-based way and triggers alerts and firebase cloud functions stores the data on firebase to steam the video to internet connected users on the web interface and a local server provide access to the local web interface to monitor cameras offline.

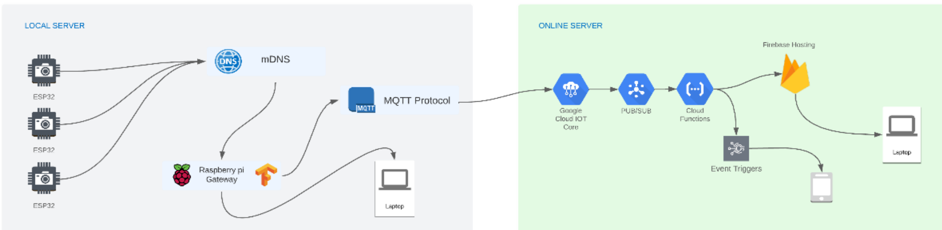


Figure 2

Architecture Overview The Architecture have two sides Local server side and Online server side, local sever side we have cameras as sensors and a local server gateway (raspberry pi) and on other side we designed the data flow on google cloud platform

Conclusion

- There are lot of scenarios out there to deploy this Edge Computing Architecture, in this paper we deployed in surveillance system which helps to detect any arm caring by a person sends an immediate alert to the local authorities. We can add as many cameras as we need to this architecture and monitor them seamlessly. The objection detection api works impressively to detect the objects in real time.

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