Utilizing a Privacy-Preserving IoT Edge and Fog Architecture in Automated Household Aquaponics.

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Abstract

Global pandemics significantly disrupt local food supply chains as was evident at the peak of the Corona Virus Disease 2019 (COVID-19). COVID-19 lockdowns adversely affected food security among mostly the poor and vulnerable. Limited interactions among farmers, inputs providers, food processors, transporters, and retailers negatively affected the provision of food. To cab food shortages, implementing the Internet of Things (IoT) based household Aquaponics in order to ensure sustainable food production, is a potentially viable solution.

Ordinarily, poor and vulnerable households are digitally illiterate. Privacy concerns adversely influence the adoption of IoT-based automation. Consequently, guaranteeing security by default among the digitally illiterate becomes necessary to improve IoT adoption. A potential solution is utilizing an architecture that ensures “Privacy by Design” in addressing IoT privacy concerns. We propose an “offline-first” architecture for automated and low-cost household Aquaponics units. The privacy-preserving architecture moves machine learning, data storage, and computation away from cloud platforms into privacy-preserving, community-hosted fog and edge computing platforms.

Keywords

Raspberry Pi, Internet of Things (IoT), Cloud Computing, Fog Computing, Edge Computing

1. Introduction

The COVID-19 pandemic brought unexpected problems on food systems, creating food insecurity in many countries. Due to travel restrictions, COVID-19 imposed shocks on all segments of food supply chains, simultaneously affecting farm production, food processing, transport and logistics, and final demand [1]. The state of food security and nutrition was already alarming before the outbreak of COVID-19: according to the “State of food security and nutrition in the world (SOFI)”, an estimated average of 821 million people were undernourished between 2016 and 2018, and the majority of the world’s hungry live in low-income countries, where 12.9% of the population is undernourished. Poor nutrition causes nearly 45% of the deaths in children under five (approximately 3.1 million children each year) [2]. These figures are increasing as a result of the COVID-19 pandemic. The 2020 Zimbabwe Humanitarian Response Plan (HRP), launched on 2 April 2020, indicates that 7 million people in urban and rural areas are in urgent need of humanitarian assistance across Zimbabwe [3].

To solve food insecurity challenges during the COVID-19 pandemic we propose a privacy-preserving IoT edge and fog architecture that will make it possible for households to have sustainable food supply. Aquaponics combines aquaculture (raising aquatic animals such as fish) with hydroponics (cultivating plants in water), in a mutually beneficial environment [4] . The two components interact via the water that cycle between them. As plants and fish grow simultaneously, fish waste is converted into nitrates, which plants use as fertilizer while they filter and clean the water for the fish [5].

Aquaponics requires maintaining the right balance among components within the ecosystem in order to guarantee optimal growth of both the vegetables and fish. Utilizing low-cost sensors, actuators and electronic equipment, an IoT application can manage the collection and use of data within the local ecosystem. Democratization of machine learning through paradigms that include TinyML and its support community makes high technology available to fields such as Aquaponics that require consistent monitoring of essential environmental parameters. Previously marginalized communities also benefit from the democratization of technology.

2.1 Cloud Computing Challenges

Cloud computing traditionally involves the delivery of on-demand computing services; from applications to storage and processing power over the internet, on a pay-as-you-go basis [7]. This architecture conveniently enables companies and individuals to not own the computing infrastructure or data centers but instead rent applications and storage from a cloud service provider. Cloud services in the global south are not reliable and mostly expensive. [8]. Another challenge of cloud computing is privacy, as individuals do not have total control of privacy settings depriving them of the ability to audit or change the processes and policies under which they must work. Another obstacle of cloud computing is the risk of losing data since customers do not have control over their data as the tools for monitoring data are not always accessible to the customers[9].

Aquaponics systems driven by IoT applications need to process data collected from the sensors into intelligible information and knowledge for the household owners. Actuators including the fish feeder and equipment such as air and water pumps also require remote monitoring. The requirement to send enormous amount of data to cloud infrastructure is not a viable option to the targeted low-income households, given the cost of the Internet and cloud services. The need for real-time control of equipment and actuators also suffer from high latency characterized by slow Internet speeds.

2.2 Edge and Fog Computing Opportunities

At the edge of the network, a vast array of sensors permits a relatively high level of processing to occur and decisions to be made locally without the need to transfer data all the time to the cloud. This allows for real-time decision making as the high latency associated with Cloud-based decision making is circumvented [6]. Computation at the edge of the network enables applications to be deployed in a sustainable way. The edge computing architecture that enables data from IoT devices to be processed at the device itself or close to the device [10]. The data is processed near the device at a local computer or server and not at traditional cloud data centers. Fog computing and edge computing are used interchangeably because both involve an intermediate level of processing and storage [9]. As Fog computing and edge computing are deployed on the Local Area Network (LAN), the connection to them and their services do not depend on the availability of an active Internet. Fog computing or cloudlet acts as a mini data center or local cloud ensuring that data is only sent to cloud when there is an anomaly. Cloudlets or fog computing also have the benefit of data sovereignty which ensures that data is subjected to the laws and governance structures within the nation it is collected, unlike data stored on cloud. Data managed on cloud platforms may be located on servers that are in another country with different laws and policies. The concept of data sovereignty is closely linked with data security because the laws and policies in a country might be able to protect data of individuals or companies [11]. Fog computing architecture typically has a Local Area Network (LAN) acting as a gateway whilst the edge environment complements it by processing data at smart devices [12]. Figure 1 differentiates the edge layer, fog layer and cloud layer.

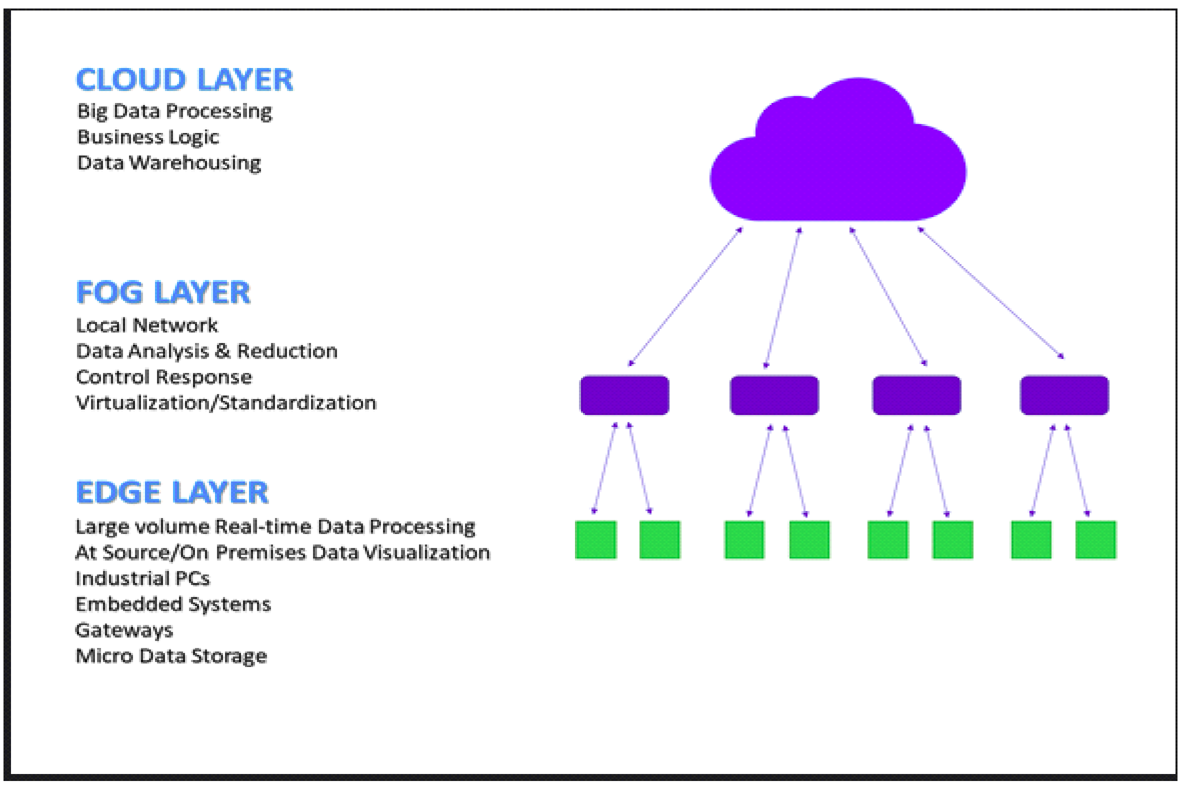

Figure 1: Overview of Edge, Fog, and Cloud Computing

3. Proposed Architecture

In utilizing the "security by design" paradigm our IoT Aquaponics system uses offline-first edge and fog computing for most of the data storage and processing. The edge and fog architecture preserves the household owners' data as it can be stored and processed at the household level, thus edge computing. Households within the community can opt to pool their data together and have it managed at a local mini-data center as opposed to utilizing the cloud, in process ensuring privacy and data sovereignty.

The IoT Aquaponics systems, shown in Figure 2, were designed at the St Peters Mbare IoT Makerspace, by high school students and youths as a proof of concept demonstrating how a poor community can solve their own food security problems using secure technology. The project's source code is available on GitHub[13].

Figure 2: Three IoT Aquaponics units developed at the University of Zimbabwe

3.1 Edge Processing

There is need to constantly monitor whether the water pump is running. Failure to detect abnormal water pump sound may result in the vegetables not getting water containing the fertilizing fish waste. We utilised a machine learning model that compares the normal sound of the water pump to the prevailing sound coming through. If the microcontroller detects a difference in sounds, which would be an anomaly, a message is sent to the system alerting the owner of the unit, otherwise no action is taken.

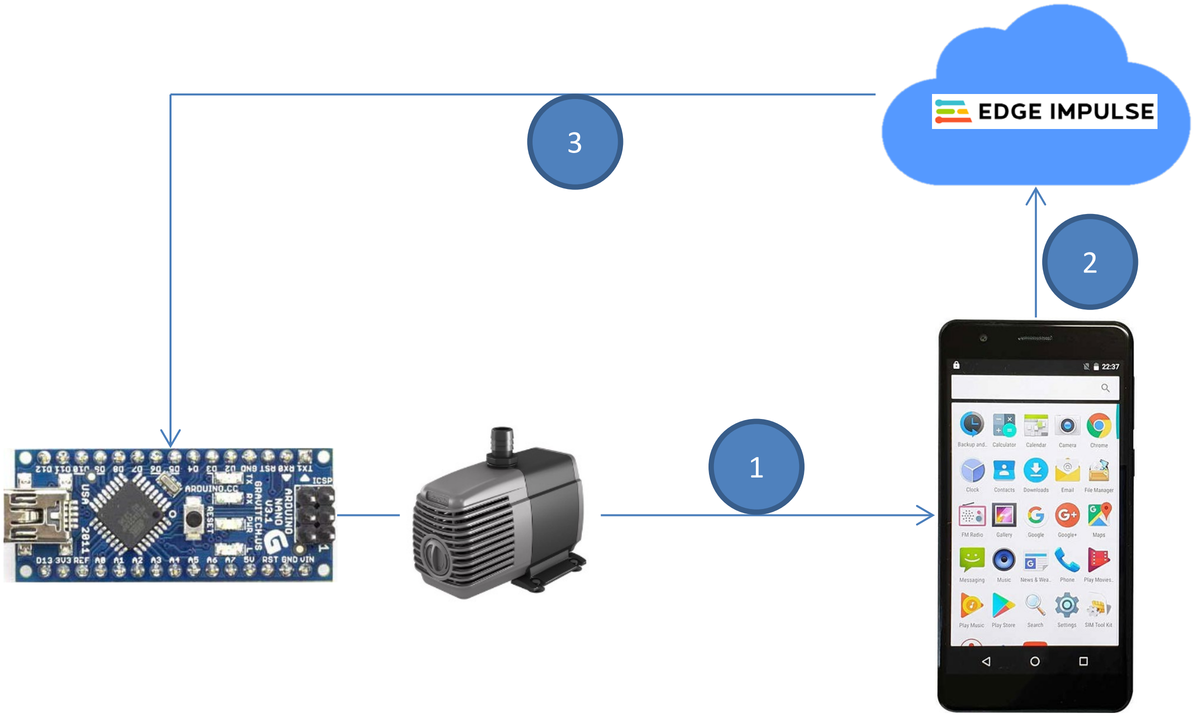

Figure 3: TinyML Machine Learning Model on a Microcontroller Edge Device

Figure 3 illustrates how the machine learning model was developed. Using the microphone, within a smartphone, the normal sound of the water pump is recorded. The recorded sound is then uploaded onto the Edge Impulse platform. Utilizing the Keras Neural Network library Edge Impulse then generated the machine learning model. The developed machine learning model was then downloaded and deployed on an Arduino microcontroller.

The offline-first approach ensures that sound data is only sent to the fog or cloud when sound anomaly is detected. Consequently data is securely retained within the edge network, in the process saving on bandwidth as well. Data will be sent from the fog layer to the cloud in the event of an anomaly detected in the audio sound recorded thus minimizing the use of cloud.

3.2 Fog Computing

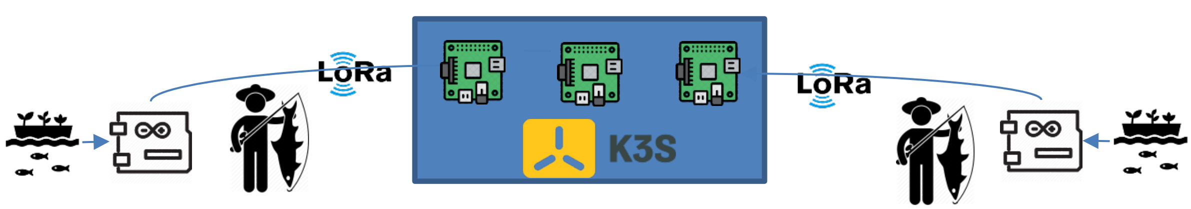

Figure 4: Fog Computing Implemented at Community Level as a Cluster of Raspberry Pis

The Aurdino microcontrollers, which provide edge computing services, have water leak, electroconductivity, pH and temperature sensors attached to it. Fog computing is implemented as a cluster of Raspberry Pi single board computers operating as a mini-data centre. A LoRa network glues together the household Aquaponics units creating the fog layer within the community. The data cluster was developed using the k3s, a lightweight Kubernetes distribution which manages the NodeRed and MongoDB docker containers.

Conclusion

The present project demonstrates the feasibility and the strong security in an IoT architecture that prioritizes processing within the edge and fog networks. Security guarantees within IoT applications will enhance adoption of the technology. It also demonstrates the possibility of implementing IoT-driven Aquaponics within households, making communities food self-sufficient. Machine learning model implemented at a local level improves efficiency and frees user from relying on internet connectivity for all processes. Although researches in edge and fog computing focused on aquaculture is still new, the results show that the adoption of mature, robust platforms for edge-enabled services, rather than customized implementations, will help address this area to grow. Expensive internet access in Zimbabwe and Africa is still a problem, and the use of edge and fog computing will help to overcome the problems related to inadequate internet. It also can ensure digital sovereignty and play a key role to meet the global challenge posed by food insecurity.

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BIOGRAPHY

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Solomon H. Kembo is a lecturer in the Department of Computer Engineering at the University of Zimbabwe. He is also founder of St Peters Mbare IoT Makerspace, a community project empowering youths from disadvantaged communities to explore open technology in solving their local problems. His current research work focuses on decentralized architectures and technologies targeted at digitally excluded and unconnected communities including edge and fog computing, decentralized machine learning and Blockchain. He is also involved with IoT interoperability efforts as a member of Internet Research Task Force's Work on IoT Semantic/Hypermedia Interoperability (WISHI).

Saulo Jacques has a PhD in ecosystem ecology with experimental research testing the impact of climate changes on the microbial community and the nutrient cycle. Former member of Aquatic Ecology Lab of Federal University of Rio de Janeiro and from the Bromeliad Working Group of the University of British Columbia currently is the research officer of Hacking Ecology, a group of developers and researchers building open source and decentralized tools for environmental research and community science.

Nevile Chitiyo graduated from the University of Zimbabwe with an electrical engineering degree. He has previously worked in electronics and developed several automation solutions suitable for the Zimbabwean environment at the Scientific and Industrial Research and Development Centre (SIRDC). He is currently working in Clamore's Research and Development division. Clamore specializes in sustainable energy solutions.