Precipitation Prediction: Using Federated Learning on IoT Devices

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Introduction

Internet of Things (IoT) devices have been growing in popularity in the past decade. They are used to automate businesses, consume less energy, and enhance overall efficiency [1]. With its rise in usage in virtually every field, and the rise of Artificial Intelligence in the world, we investigate combining IoT with Machine Learning (ML) to explore low power consumption in our smart models.

Federated Learning (FL), a distributed ML strategy, is used on IoT devices to enable on-device training, keep the client data private and update the global model [2].

This project presents a simplified implementation of FL for environmental monitoring using diverse IoT devices, inspired by the approach of Ficco et al. [3]. This adaptation uses sensors to collect temperature and humidity data at 2 different locations, and use it to predict precipitation, based on a historical weather data-trained model that can identify the relationship between these parameters.

Methodology

This project implements a small-scale IoT network with two edge nodes and one central server to demonstrate federated learning for environmental monitoring. The edge devices—**an ESP32 board** and **an Arduino™ MKR Vidor 4000**—collect **temperature and humidity** data using an **SHTC3 sensor** at different locations. A **Raspberry Pi 5** serves as the central FL server as shown in Fig. 1.

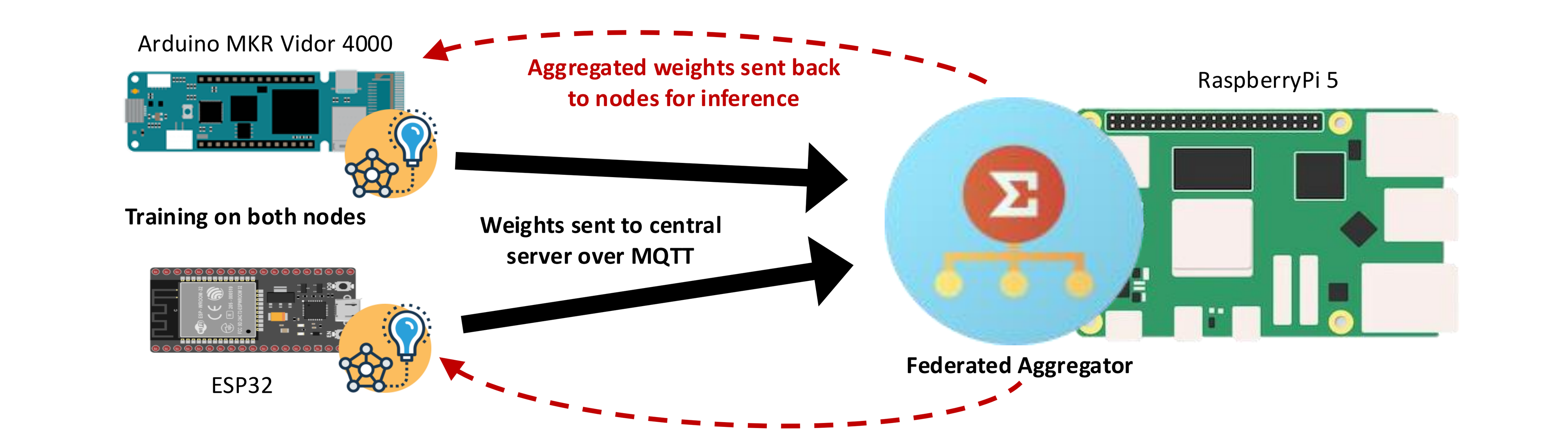

Fig. 1. An overview of the methodology for the implementation

To analyze precipitation patterns, real-time sensor data is compared with historical weather data sourced from Visual Crossing Weather. A predictive model is trained to determine how temperature and humidity fluctuations impact precipitation likelihood, providing a foundation for edge-based precipitation forecasting.

Approach

On-device Training
- Edge node collects its own data
- Each edge node trains its own model

Privacy Preservation
- Raw data never leaves the device
- Only model weights are shared with server ensuring privacy

Model Aggregation
- Local server aggregates model weights from local models
- Global model improves performance

Efficient Communication
- MQTT protocol for light-weight data exchange
- Less data transmitted
- Low power consumption

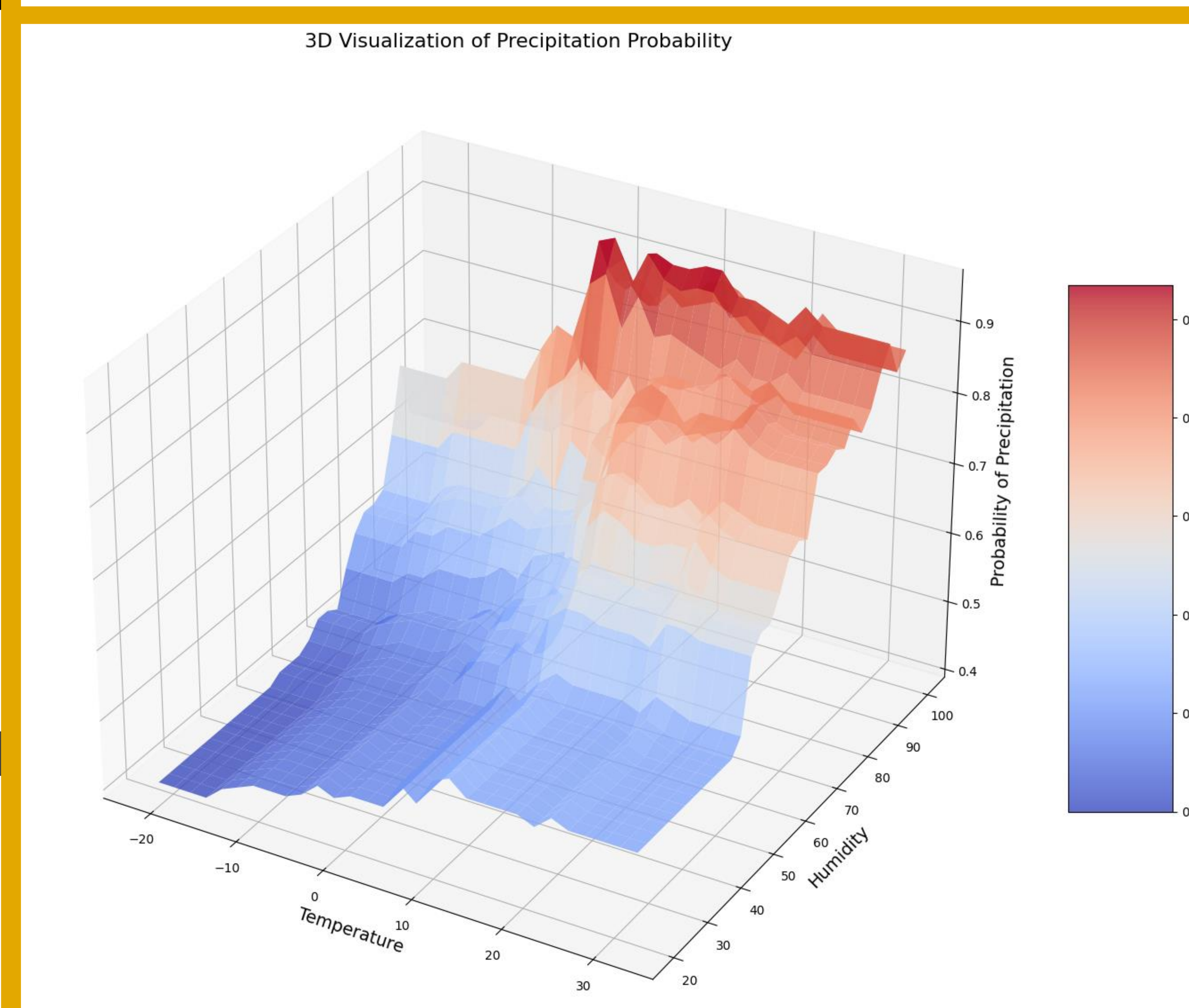

Fig. 2. Data trends from January 2022 to May 2024 [4]

Preliminary Results

	Precision	Recall	F1-score	Support
0 (No precipitation)	0.98	0.97	0.97	633
1(precipitation)	0.96	0.98	0.97	611
Accuracy			0.97	1244
Macro	0.97	0.97	0.97	1244
Weight	0.97	0.97	0.97	1244

Ongoing Work

- **Scaling Model Complexity:** Train larger models beyond the Rainforest model to handle more complex environmental data directly on edge devices.
- **Advanced Model Architectures:** Explore the feasibility of deploying deep learning models such as Conv2D for spatial weather patterns, comparing them with traditional machine learning models.
- **Federated Aggregator Performance Analysis:** Conduct a comparative study of different federated aggregation techniques (e.g., FedAvg, FedProx, or FedOpt) to assess their impact on prediction accuracy and model convergence.
- **Expand Use of Edge Nodes:** Use multiple nodes to be kept at different locations and evaluate the aggregation performance.

References & Acknowledgments

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