AquaBlock: A Distributed Ledger for Efficient Total Dissolved Solids Data in Fisheries in Smart Aquaculture

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***Abstract*—TDS, or total dissolved solids, is a key indicator that measures the total number of dissolved particles per unit of water. These particles can be minerals, metals, and other pollutants that are present in water due to various anthropogenic activities. Fertilizer runoff and solid waste pollution, examples of negative anthropogenic activities, will cause TDS levels to fluctuate and this imbalance can lead to destruction of marine ecosystems. Analyzing its effect specifically in aquaculture, or fish farming, can be beneficial in maintaining optimal environments for fish production. Today, smart aquaculture incorporates different technological advancements like water meters or sensors that can be used to determine the health and quality of the water body. This paper demonstrates how an IoT device, configured with a TDS Meter Sensor, was used to extract TDS data from different samples and stored in a Distributed Ledger environment. Data was extracted from the Distributed Ledger environment for further analysis to develop conclusions on the effect of pollutants on water samples.**

***Index terms*—** Aquaculture; Total Dissolved Solids (TDS); Internet-of-Things (IoT); Smart Aquaculture; Distributed Ledger.

I. Introduction

Fish is an important superfood known for having high amounts of Omega-3 Fatty Acids and being a great source of minerals. The human body doesn't naturally produce Omega-3 and therefore, fish has increasingly become more common in people's diets to maintain healthy heart and brain function. Around the world, more than 3 billion people rely on fish as their main protein intake and it accounts for 17% of the total world's meat consumption [1]. Fish consumption is even more staggering in developing countries as their industries employ 97% of the world's fishing workforce with majority being small independent businesses [2]. This industry itself is becoming progressively competitive and is expected to grow annually by 6.35% as the world now consumes more farm-raised fish than wild-caught [3].

Aquaculture, the practice of raising fish, is only successful in ideal environmental conditions. Poor water quality can significantly hinder the productivity of fisheries as pollutants (fertilizer run-off, acid rain, organic waste, and pesticides) are a primary irritant and common cause of fish diseases. These ecosystems require consistent and stable levels of minerals and dissolved solids and fluctuations in these metrics disrupt fish growth and fish breeding practices [4]. Water quality conditions can be rationalized using the Total Dissolved Solids (TDS) measurement which signifies the concentration of any solid, organic and inorganic, in a liquid (expressed in parts per million - *ppm*).

As the aquaculture industry becomes more competitive, margins of success for many farmers are slim. Relying on core metrics like TDS to evaluate conditions for fish farming are crucial for consistent yields. Traditional practices of predicting fishing yields are no longer suitable for consistent revenue, especially for small scale farmers. The Alaska Department of Fish and Game Division of Habitat and Restoration conducted a study to evaluate how sensitive fresh water fish are to TDS fluctuations. They found that any TDS concentration around 750 *mg/L* (equivalent to 750 *ppm*) had a profound effect on fertilization and hatching rates of different salmon species [5]. Therefore, TDS is a valuable metric that aquatic farms need to monitor for maintaining fish health.

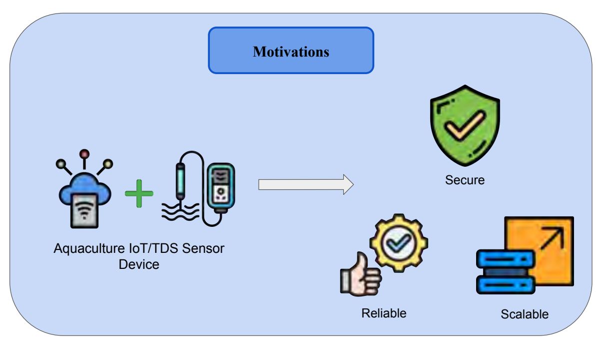

Fig. 1: Motivations for Distributed Ledger application.

Collecting TDS data to understand water quality can help fish farmers adjust and cater to different aquaculture techniques for optimal fish production. Internet of Things (IoT), devices fixed with sensors to collect and share data over the Internet, can be utilized as "smart aquaculture" to process water quality data for fish farming applications. Proper data security and storage principles must also be followed in order to maintain a secure data pipeline that is not prone to cyber attacks, application vulnerabilities, and data loss. Relying on centralized systems for data storage and security can be risky due to single points of failure, which compelled us to combine Distributed Ledger technology that supports smart aquaculture IoT devices. This decentralized system will be more secure, scalable, and reliable for both data consumption and long-term data storage. Some of the motivations for the current paper are provided in Fig. 1.

The paper is organized as follows: We elucidate on the problems and propose a state of the art solution in Section II. In Section III we discuss previous works on water quality indicators in aquaculture and Distributed Ledger usage in smart farming. A novel architecture for the proposed Distributed Ledger system are explained in Section IV. For validating the current system we implement and give the results in Section V. Finally, we discuss the conclusions and future directions for the current paper in Section VI.

II. State-of-the-Art Contributions

A. Problems discussed

- Poor water quality hinders the productivity of fisheries.
- Aquaculture requires ecosystems that consist of stable levels of minerals and dissolved solids.
- Aquaculture profitability margins are slim due to the unpredictability of consistent yields.

B. Proposed Ideas in the Current Paper

- Encouraging aquaculturists to rely on computative metrics to predict and maintain yields.
- Increasing profit margins for aquaculture by preemptively assessing water quality conditions.
- Enforcing principles of data governance and security for better protection and efficient consumption and production of data.

C. State-of-the-art Solutions

- IoT Devices with sensors that monitor water quality metrics like TDS allow aquaculturists to accurately assess water quality in fisheries.
- Decentralized Distributed Ledger systems for data governance will introduce more security to retain important data transactions.
- Implementing data pipelines that extract data from IoT Devices, load data to Distributed Ledger, and transform data for analysis (ELT) can allow aquaculturists to deliver consistent yields sustainably.

III. Related Prior Works

A. Previous Work on Water Quality Monitoring in Aquaculture

Many researchers have designed systems to monitor water quality for aquaculture purposes. Here we will elaborate on some of the unique ways and benefits IoT devices have been used to improve aquaculture.

[6] developed a low-cost IoT device using an Arduino microcontroller to monitor key water quality metrics—TDS, temperature, and pH—in an aquaponics system. Aquaponics combines aquaculture and hydroponics, where fish waste provides nutrients for plants, and plants help purify the water. This cycle is highly sensitive to water quality; a lack of essential minerals can harm plants, reduce fish nutrition, and disrupt the system. The device processes analog and digital outputs from various sensors to ensure optimal conditions for both plants and fish.

[7] presents an IoT-based aquaculture monitoring system for assessing water quality in ponds and fisheries using pH, temperature, and turbidity sensors. Sensor data is transmitted to Ubidots, a cloud platform for real-time analysis and management. The system was successfully implemented in a tilapia tank, producing time-based charts and graphs to visualize water quality data.

[8] proposes an IoT-based Smart Aquaculture System (ISAS) that not only detects water quality anomalies but also autonomously activates aeration to maintain optimal fish conditions. The system uses pH, temperature, dissolved oxygen, and water hardness sensors to monitor water quality. A fuzzy inference process—converting sensor data into fuzzy values (e.g., low, medium, high) and then into a precise output—determines whether to trigger the aerator.

[9] introduces an IoT-based wireless sensor network (WSN) for real-time monitoring of rural river water quality using turbidity, pH, and temperature sensors. Data is transmitted to a cloud server for big data analysis and processing through multi-layered neural network models. The system also includes an SMS alert feature to notify authorities of water quality abnormalities, enabling timely pollution control measures.

The projects discussed above utilize multiple water sensors to assess water quality and support decision-making; however, relying on various sensors can be inefficient and lead to inconsistencies, as conflicting readings may arise between sensors. This complicates real-time interpretation and increases costs related to procurement, installation, and maintenance—making these systems less feasible for fish farmers who must balance operational costs with profitability to sustain their livelihoods. Additionally, most existing systems rely on centralized data storage, which introduces risks such as single points of failure and vulnerability to cyberattacks. In contrast, our paper proposes a cost-effective solution using a single TDS sensor, a reliable indicator of overall water quality, integrated within a decentralized (Distributed Ledger-based) system. This approach enhances security, reliability, and scalability for aquaculture operations. Table I compares the reviewed systems in terms of cost and data storage architecture, with relative cost estimates based on referenced sources.

B. Previous Work on Distributed Ledger for Smart Aquaculture

Distributed Ledger has been explored in a variety of industries but has been underutilized in smart aquaculture. Many of the benefits and success of Distributed Ledger in other fields can also translate and improve how data is collected, managed,

TABLE I: Comparison of Aquaculture Monitoring Systems Based on Cost and Data Storage

Author	Monitoring System Cost (per unit)	Data Storage Type
Rahayuningtyas et al. [6]	26.89 USD	SD Card (Centralized)
Bachtiar et al. [7]	46.90 USD	Cloud Database (Centralized)
Tsai et al. [8]	237.70 USD	Cloud Database (Centralized)
Proposed System	**17.78 USD**	**Distributed Ledger Based**

and accessed by small businesses and corporations involved in fish farming.

Distributed Ledger, as the name suggests, is a sophisticated architecture for data storage where each block (node) is responsible for a piece of data as well the reference to the previous block for traceability. Tampering is extremely prohibited as attempting to modify even one block will result in its hash (the reference needed for that block to be traceable in the chain) to be rewritten. This will compromise the integrity of only an individual copy of the chain where tampering was attempted, but won't effect other copies of the chain in the network of computer systems the Distributed Ledger is stored - a strong quality of security and immutability.

An interesting aspect of Distributed Ledger is that it maintains strong security without promoting privacy. Institutions that use Distributed Ledger for storing confidential and personally identifiable data have privacy built into the Distributed Ledger by storing encrypted data in the Distributed Ledger that can only be decrypted through decryption keys. We will explore how encryption and decryption will play a role in storing water quality data.

At present day, there are many research studies that explore the benefits of Distributed Ledger for its traceability rather than incentive or payment, primarily in the supply chain sector. [10] shows the Distributed Ledger technology can be a well-suited for improving the management of fisheries by using cryptography proofs as a means to govern if fishers in a supply chain network are following government standards regarding the sustainability and quality practices for seafood. [10] also cites a recent project to reduce supply wastage in the aquaculture industry. Called Net 360, the Distributed Ledger-implemented project tracks the lifecycle, repurposing, and recycling of fishing nets and the Distributed Ledger technology being used ensures that the traceability of nets is secure, well-managed, and transparent to ensure all stakeholders (individual customers and businesses) that purchased nets are coming from sustainable sources.

[11] discusses the current day applications of Distributed Ledger technology in the seafood supply chains. The researchers delve in depth regarding the types of Distributed Ledger that are currently being implemented such as public Distributed Ledger, private Distributed Ledger, and Distributed Ledger consortiums. The researchers also share how smart contracts are integral in the aquaculture-based chains as they ensure accountability and transparency to both the stakeholders and customers. [11] concludes with future hopes in how DeFi (decentralized finance) solutions can help developing countries, specifically in the aquaculture industry, by tokenizing aquaculture assets like fish stocks.

In Fig. 2, [12] shows how typical Distributed Ledger applications, using Hyperledger Sawtooth, are being implemented to improve supply chain in the aquaculture industry by giving consumers more transparency into food security through parameters like temperature, humidity, possession, etc.

This current paper will explore how Blockchain-Distributed Ledger, as opposed to traditional tools and technologies, can be used as a better practice mechanism for better storing and distributing highly sensitive and valuable water quality data.

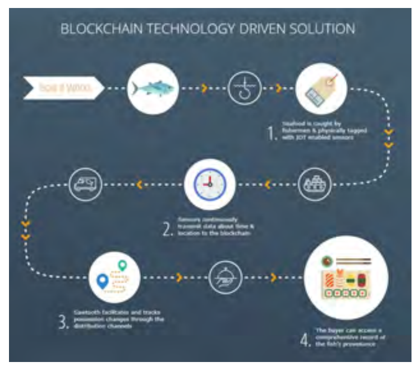

Fig. 2: Typical Distributed Ledger Applications in Aquaculture Supply Chain.

IV. Proposed State-of-the-Art Architecture

The proposed architecture in this paper follows the traditional ELT design. The architecture and data pipeline will demonstrate how data will be extracted from sensors, how the data is loaded and stored for downstream analytical operations, and how the data will be transformed to perform those analytical operations and gain important insights on water quality in fisheries.

A. Data Extraction from IoT Sensors

For simplification, we focused on a single parameter of water quality, TDS, and extracted data using an arduino-enabled TDS Sensor. This sensor can be broken up into three parts that together facilitate the extraction and translation of TDS measurements from water samples: a signal transmitter board, a TDS Water Probe, and three interface cables for power and analog signal connection. Retrieved from [13], Fig. 3 shows the parts used for extracting TDS data.

Fig. 3: Necessary Components for TDS Measurement

Results retrieved from this setup are very consistent given that the AC Signals aren't as prone to irregularities and polarizations and the TDS Water Probe, provided by CQRobot, were designed and stable to be immersed in water for longer lengths of time for accurate measurements. Because our design requires Raspberry Pi for downstream data processes, a fourth part is required (ADS1115 16-bit AD conversion module) to convert the signals suitable for the Raspberry Pi system. Fig. 4 below shows the hardware setup we are proposing for data extraction.

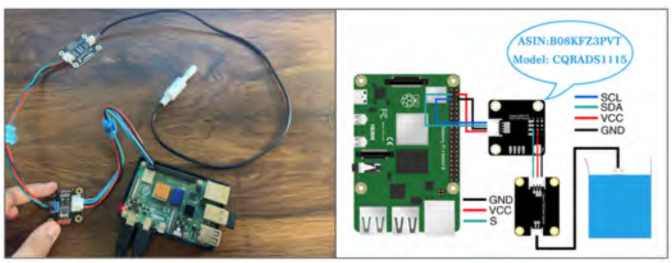

Fig. 4: TDS Hardware Architecture Setup

There is also extensive software setup involved to make sure all the components mentioned above in the hardware setup are working as expected. [13] provides the instructions for installing the TDS Sensor application for Raspberry Pi and configuring the signal and voltage interpretation by bootstrapping two python files: CQRobot_ADS1115.py and ADS1115_Read Voltage.py

Sample source code is shown below in Fig. 5

B. Data Load and Storage in Distributed Ledger

A Distributed Ledger, at the bare minimum, stores a series of blocks, each with transactional information, it's unique hash, and the hash of the previous block. As mentioned before, storing the previous hash allows the blocks to communicate and co-exist in a "chain-like" manner. In order to process and store the data effectively using the Raspberry Pi's compute resources, we built our own simple Distributed Ledger to demonstrate an example of how to store data. Depending on user requirements, the Distributed Ledger can be implemented differently or use a third-party service as per needs.

As described in [14], we developed a block class and Distributed Ledger class in Python to structure our Distributed Ledger. The block class stores transactional data and unique hash values for both itself as well as the reference to the previous block to operate in the Distributed Ledger. In order to calculate the hash, we are importing the hashlib library

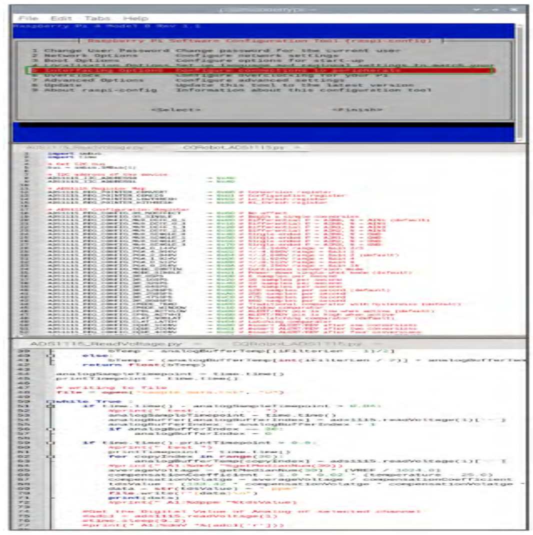

Fig. 5: TDS Software Architecture Setup

and performing sha-256 encryption. This encryption logic is stored within the calculate_hash() method within the Block class. Below is our implemented block class that we are using for loading data.

```
class Block:
    def __init__(self, index, timestamp, data,
     previous_hash):
        self.index = index
        self.timestamp = timestamp
        self.data = data
        self.previous_hash = previous_hash
        self.hash = self.calculate_hash()

    def calculate_hash(self):
        hash_string = str(self.index) + str(
    self.timestamp) + str(self.data) + str(
    self.previous_hash)
        return hashlib.sha256(hash_string.
    encode()).hexdigest()
```

Now that we are able to create blocks to store in a Distributed Ledger, we still need to implement functionality to interact with the blocks. Operations like creating a chain, adding blocks to the chain, getting most recent blocks, etc. are all implemented in the Distributed Ledger class as shown below.

Listing 1: Distributed Ledger Class

```
        class DistributedLedger:
        def __init__(self):
        self.chain = [self.create_head_block()
    ]

        def create_head_block(self):
        return Block(0, date.datetime.now(), [
    "initial_block_no_stored_data"], "0")

        def get_latest_block(self):
```

```
        return self.chain[-1]

        def add_block(self, block):
        block.previous_hash = self.
    get_latest_block().hash
        block.hash = block.calculate_hash()
        self.chain.append(block)

        def is_valid(self):
        for i in range(1, len(self.chain)):
        curr, prev = self.chain[i], self.chain
    [i-1]
        if curr.hash != curr.calculate_hash()
    or curr.previous_hash != prev.hash:
        return False
        return True
```

With this code, users can add blocks that store water quality data and easily access them through the defined functions in the Distributed Ledger class. Below is simple logic to combine data into a pandas dataframe from multiple sources and then iteratively add partitions of the data to multiple blocks as soon as the data is ready to be processed.

```
# combining data into single df
df = pd.concat([home_df, spring_df, lake_df],
    ignore_index=True)
num_of_blocks = 30
for i in range(0, num_of_blocks):
    data = df.iloc[i].to_dict()
    new_block = Block(i+1, date.datetime.now()
    , data, "")
    Distributed Ledger.add_block(new_block)
```

To reiterate like before, this is a simplified design of a Distributed Ledger to demonstrate a potential architecture and implementation can differ depending on specific security requirements and needs.

C. Data Transformation and Analysis

In order to do analysis on the data, we wrote some simple logic to iterate through the chain and retrieve the data stored in each block. Initially, we had the data in one large pandas dataframe and partitioned it to load it to the Distributed Ledger. Now, we are doing a reversal of that procedure and processing the data back into a pandas dataframe to do some analysis. Here's one example way on how to do so.

Listing 2: Reading Blocks from Distributed Ledger

```
        df_read = pd.DataFrame()
        for block in Distributed_Ledger.chain:
        print(f"Block#{block.index}\nTimestamp
    :␣{block.timestamp}")
        print(f"Data:␣{block.data}\nHash:␣{
    block.hash}")
        print(f"PreviousHash:␣{block.
    previous_hash}\n")
        if block.index > 0:
        df_read = pd.concat([df_read, pd.
    DataFrame([block.data])], ignore_index=
    True)
```

This code is not only printing the blocks within the chain but also loading the water quality data into a pandas dataframe, which can later be manipulated and used with other libraries to generate plots and analysis.

V. Experimental Results

Using the above proposed architecture, we wanted to sample and store data from three very distinct water sources: home (tap), spring (store-bought), and lake water. We first sampled the water using traditional plastic water bottles as seen in Fig. 6. In order to reduce as much variance as possible, all measurements were taken in one location for approximately 10 seconds to get stable readings. This data was then compiled by the sensor's starter code into a .txt file that is compatible to be processed by our Distributed Ledger implementation.

Fig. 6: Various Water Sampling

The Distributed Ledger implementation is able to read the .txt files for all three water types into a pandas dataframe and each reading was then converted to a dictionary in python to be ingested and stored as data per block in the Distributed Ledger. Below is the code of how each .txt file was processed and partitioned into the Distributed Ledger.

Listing 3: Loading and Partitioning Water Data into Distributed Ledger

```
        file_info = {
                "home_water.txt": "Home",
                "spring_water.txt": "Spring",
                "lake_water.txt": "Lake"
        }

        dfs = []
        for file, label in file_info.items():
        df = pd.read_csv(f"water_data/{file}",
        names=['Total_Dissolved_Solids_(PPM)'
    ],
        on_bad_lines='skip')
        df['Water_Type'] = label
        dfs.append(df[['Water_Type', '
    Total_Dissolved_Solids_(PPM)']].head(10))

        combined_df = pd.concat(dfs,
    ignore_index=True)
```

```
        for i, row in combined_df.iterrows():
            data = row.to_dict()
            new_block = Block(i+1, date.datetime.
    now(), data, "")
            Distributed_Ledger.add_block(new_block
    )
```

Once the data was processed into the Distributed Ledger, as shown in the Data Transformation and Analysis subsection, we extracted the data back into a pandas dataframe for analysis and printed the contents of each block as shown in Fig. 7.

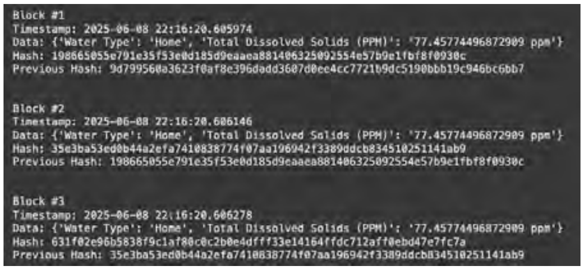

Fig. 7: Block Content/Metadata Output

This pandas dataframe was later used for plotting the results with the matplotlib library to show how PPM fluctuated across the 10 readings for the different water types. This is a simple example of how data can be analyzed after extracting from a Distributed Ledger as shown in Fig. 8.

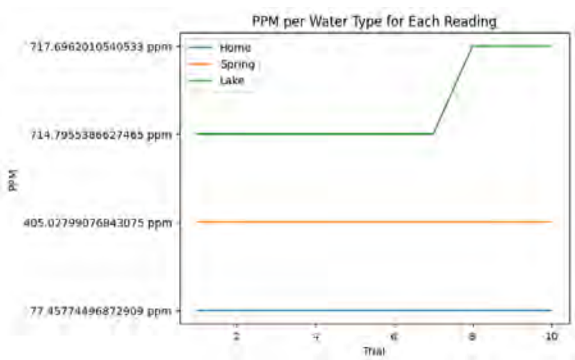

Fig. 8: PPM per Water Type for Each Reading

VI. Conclusion and Future Direction

This paper proposes a novel architecture that can help fish farmers assess water quality in real time with an efficient data metric/indicator, TDS. Our present paper introduces a data pipeline that integrates Distributed Ledger technology to ensure data governance and security. We assume that the proposed state-of-the-art architecture would be extremely beneficial for fish farmers, especially those living in second and third world countries, as it is cost efficient and can help increase profit margins as fisheries' water quality can be monitored by fish farmers, who can then take adequate actions if necessary. Our application can be improved and provide real-world assistance in fisheries with the development of a beneficial mobile application that can track TDS data and push out notifications if there are any data abnormalities/suggestions to the fish farmer. Our system is a simplified Distributed Ledger-based design and we hope that in the future that our ideas will be enhanced and improved upon for actual assistance in fisheries.

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