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Real-Time Water Monitoring System for Tilapia farms

Presented by:

Ouldbabaali Mohamed el Amine

Derradji Houssem

Proposed and Directed by:

Dr. Chadli Samir

Dr. Toubal Abdelmoughni

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Dedication

بسم الله الرحمن الرحيم والحمد لله

We dedicate this project thesis to our families and many friends. A special feeling of gratitude to our loving parents, who tirelessly encouraged us and supported us throughout our academic path, and to all our siblings who have never left our sides and are very special.

We also dedicate this project thesis to my friends who have supported me throughout this journey such as Mossaab Benhadjer, Mossaab Mazighi and Youcef Ramoul who shared their knowledge with us which helped us realize this project. we will always appreciate their support and all the things they have done.

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We dedicate this work and give special thanks to our best friends for being there for us throughout the Master's program. All of you have been our best cheerleaders.
Above all, we dedicate this project thesis to the Almighty God above. Finishing this manuscript is a great opportunity to express our whole-hearted thanks and many praises unto him.

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Abstract:

Tilapia farming is an increasingly growing industry that provides a source of protein worldwide. However, the sustainability of these aquaculture systems is disturbed by environmental threats that can affect the quality of water, such as salinity, pH, temperature, and turbidity. These parameters present danger for the health and growth of tilapia, and any change that occurs would increase risk in mortality rates and economic losses.

This project presents the need for consistent monitoring of water in tilapia aquaculture farms. Traditional methods of water quality are not efficient, time-consuming, and most of the time would not succeed in providing real-time data, which could harm the fish population, Tilapia farmers face challenges in maintaining the best possible water conditions, as the lack of immediate notification can result in late reaction to environmental danger leading to growth problems, disease spreading, and even massive fish mortality.

This system utilizes advanced sensors integrated with IoT technology, creating a network of real-time monitoring devices. These sensors provide a constant measure of the water's salinity, pH, temperature, and turbidity values, controlled by an ESP32 card. The collected data is to be processed and analyzed to notify the business owner of potential threats to the fish.

The development of this system provides a significant contribution towards the advancement of aquaculture offering a cost-effective, efficient and scalable solution for tilapia farms ensuring the health of their fish and the sustainability of their business, The ability of the system to monitor and notify about threats lead to better managed farms providing better production results.

Keywords: Aquaculture, Tilapia Farming, Water Quality Monitoring, IoT, Real-Time Data, ESP-32.

Résumé:

L'élevage de tilapia est une industrie en pleine croissance qui fournit une source de protéines dans le monde entier. Cependant, la durabilité de ces systèmes aquacoles est perturbée par des menaces environnementales pouvant affecter la qualité de l'eau, telles que la salinité, le pH, la température et la turbidité. Ces paramètres présentent un danger pour la santé et la croissance du tilapia, et tout changement pourrait accroître le risque de mortalité et de pertes économiques. Ce projet souligne la nécessité d'une surveillance continue de l'eau dans les élevages de tilapia. Les méthodes traditionnelles d'analyse de la qualité de l'eau ne sont pas efficaces, prennent du temps et ne permettent souvent pas de fournir des données en temps réel, ce qui pourrait nuire à la population de poissons. Les pisciculteurs de tilapia ont du mal à maintenir les meilleures conditions d'eau possible, car l'absence de notification immédiate peut entraîner une réaction tardive aux dangers environnementaux, conduisant à des problèmes de croissance, à la propagation de maladies et

même à une mortalité massive des poissons. Ce système utilise des capteurs avancés intégrés à la technologie IoT, créant un réseau d'appareils de surveillance en temps réel. Ces capteurs fournissent une mesure constante des valeurs de salinité, de pH, de température et de turbidité de l'eau, contrôlés par une carte ESP32. Les données collectées doivent être traitées et analysées pour informer le propriétaire de l'entreprise des menaces potentielles pour les poissons. Le développement de ce système apporte une contribution significative à l'avancement de l'aquaculture en offrant une solution rentable, efficace et évolutive pour les élevages de tilapia, garantissant la santé de leurs poissons et la durabilité de leur entreprise. La capacité du système à surveiller et à notifier les menaces permet une meilleure gestion des exploitations piscicoles et de meilleurs résultats de production.

Mots-clés: Aquaculture, L'élevage du tilapia, Surveillance de la qualité de l'eau, IoT, Données en temps réel, ESP-32.

ملخص:

تعتبر زراعة البلطي صناعة متنامية بشكل متزايد توفر مصدرًا للبروتين في جميع أنحاء العالم. ومع ذلك، فإن استدامة هذه الأنظمة الزراعية المائية تتأثر بالتهديدات البيئية التي يمكن أن تؤثر على جودة الماء، مثل الملوحة ودرجة الحموضة ودرجة الحرارة والتعكر في المياه. تشكل هذه المعايير خطرًا على صحة ونمو البلطي، وأي تغيير يحدث قد يزيد من خطر ارتفاع معدلات الوفيات والخسائر الاقتصادية.

يقدم هذا المشروع الحاجة إلى مراقبة مستمرة للماء في مزارع البلطي المائية. الطرق التقليدية لمراقبة جودة الماء ليست فعالة وتستغرق وقتًا طويلًا، وغالبًا ما لا تنجح في توفير بيانات في الوقت الفعلي، مما قد يضر الأسماك. يواجه مزارعو البلطي تحديات في الحفاظ على أفضل الظروف المائية الممكنة، حيث يمكن أن يؤدي نقص الإخطار الفوري إلى رد فعل متأخر للخطر البيئي مما يؤدي إلى مشاكل في النمو وانتشار الأمراض وحتى موت الأسماك بشكل جماعي.

يستخدم هذا النظام مستشعرات متقدمة مدمجة مع تقنية إنترنت الأشياء، مما يخلق شبكة من انظمة المراقبة في الوقت الفعلي. توفر هذه المستشعرات قياسًا مستمرًا لقيم ملوحة الماء, درجة الحموضة, درجة الحرارة و تعكر المياه، ويتم التحكم فيها بواسطة بطاقة esp 32 يجب معالجة البيانات التي تم جمعها وتحليلها لإخطار مالك العمل بالتهديدات المحتملة للأسماك.

يوفر تطوير هذا النظام مساهمة كبيرة نحو تقدم تقنيات الزراعة المائية من خلال تقديم حل فعال من حيث التكلفة والكفاءة وقابلية للتوسع لمزارع البلطي مما يضمن صحة أسماكهم واستدامة أعمالهم. تؤدي قدرة النظام على المراقبة والإخطار بالتهديدات إلى إدارة أفضل للمزارع مما يوفر نتائج إنتاجية أفضل.

الكلمات المفتاحية **:**الزراعة المائية، زراعة البلطي، مراقبة جودة الماء، إنترنت الأشياء، البيانات في الوقت الفعلي، ESP-32.

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List of Acronyms

AC: Aquaculture
ADC: Analog to Digital Converter
DAC: Digital to Analog Converter
DO: Dissolved Oxygen
GPIO: General Purpose Input / Output
IOT: Internet of Things
IP: Internet Protocol
I2C: Inter-Integrated Circuit
JSON: Java Script Object Notation
PH: Potential of Hydrogen
RTD: Real-time Data
UDP: User Datagram Protocol
UART: Universal Asynchronous Receiver/Transmitter
UI: User Interface
SPI: Serial Peripherical Interface
TCP: Transmission Control Protocol
TDS: Total Dissolved Solids
VREF: Voltage Reference

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Introduction

General Introduction

Aquaculture production has increased steadily in recent years and is the fastest growing food production sector and has become a valuable component of national development and poverty reduction plans in many areas of the world [1].

Aquaculture is one of the fastest growing sectors of the global livestock production [2], approximately 40% of fish from aquaculture is originated from tilapia production [3]. Aquaculture is currently playing, and will continue to play, a big part in boosting global fish production and in meeting the rising demand of fishery products.

Water quality has a significant impact on the growth of tilapia fish at different stages of their life. Factors such as temperature, dissolved oxygen, pH, and nutrient concentrations in the water can affect the growth and productivity of tilapia [4].

Tilapia AC is a vital source of protein around the globe, however it is quite challenging to maintain optimal water conditions for fish growth and health, traditional water monitoring methods are often inefficient and fail to provide RTD, workers not reacting to the environmental changes in time can cause critical consequences such us diseases and even mass die-offs resulting in economic losses.

In this master thesis, we will propose an Intelligent system that automatically provides RTD about the water quality in-order to ensure optimal reaction time to potential threats that may affect the health and growth of Tilapia which gives time for business workers to react in time.

In the first chapter we will be getting into the generalities of tilapia farming, in the second chapter we will get to the System components design, and in the third chapter we will get to the implementation, calibration, test and results.

Chapter I:

General Information on Tilapia Farming

1.1. Introduction

Food security is a very important determinant of whether people can lead an active and healthy life, because it determines their access to foods required to meet nutrient needs, food security occurs when all people, all of the time, have access to sufficient, safe, affordable, and nutritious food for a healthy diet, demand for food is increasing, driven by a range of population and demographic changes: population growth, changes in population structure, consumption growth, and urbanization [11].

Most of the world's countries are in the process of achieving and maintaining food security through the search for the necessary resources, and the fisheries sector is a critical strategic sector given the significant potential role it can play in nutrition, especially by contributing effectively to the supply of renewable fish. [13]

The growth in population proposed a threat such as in China where food security became a challenge in the country which led to searching for different sources of nutrition, one of the contributing sources is Tilapia farming, China's tilapia industry started in the 1960s, entered a period of rapid development after the 1990s, began to slow down in 2008 and entered a stable period from 2015 to 2018 with stable production about 1.58 million tons, tilapia farming is practices throughout the world. the largest producer country is China (1,241,410 t), followed by Indonesia (1,172,633 t), Egypt (954,154 t) and Thailand (205,971 t) (FAO, 2022) [12].

1.2. History of tilapia industry

Aquaculture Historical Review

AC is the farming of aquatic organisms, including fish, mollusks, crustaceans and aquatic plants, in freshwater, brackish-water and seawater environments. Capture fisheries, on the other hand, are the exploitation of aquatic organisms by the public as a common property resource, with or without appropriate licenses. Aquaculture's contribution to total global fisheries landings was very low during 1950-1970, ranging from only 638,577 Mt (3.2%) in 1950 to 5.2% in 1970 [15].

Global AC production continued to grow to 9.6% in 1980 and 16.3% in 1990. In the 1990s and early 2000s, this production grew at an out- standing rate to reach an annual rate of 32.1% in 2000, 34% in 2001 and 35.2% in 2002 (Fig. 1.1) [15].

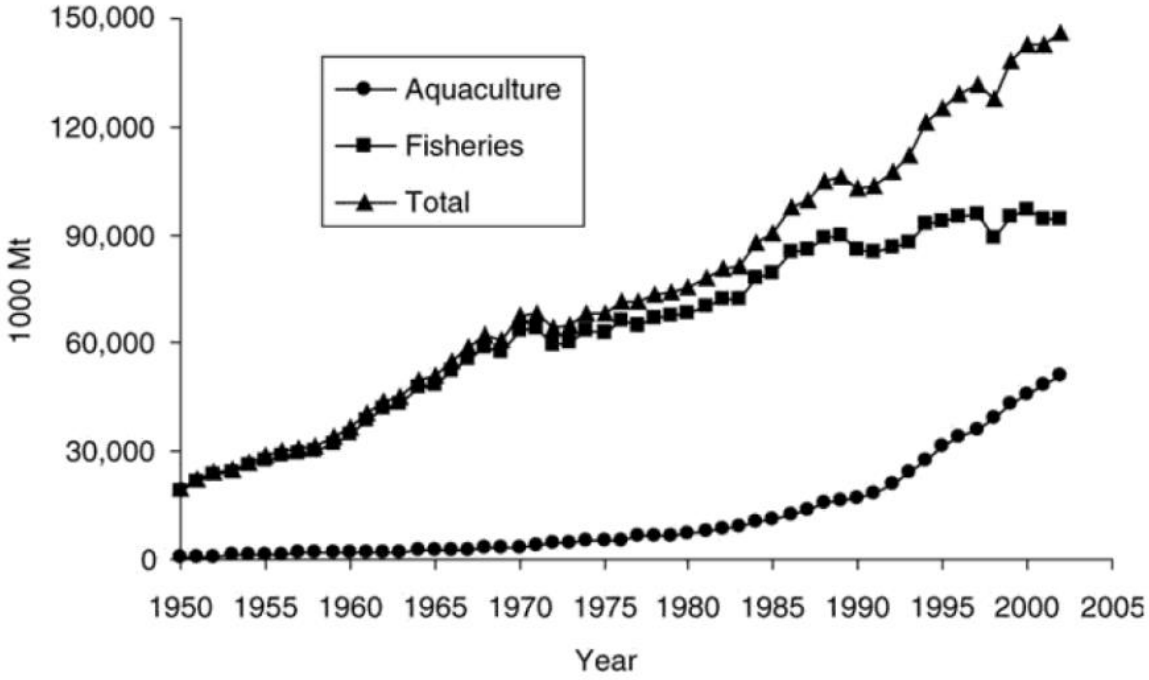


Figure I 1- Continental Production (Mt) of farmed tilapia during 1950-2002

The average annual compounded growth rate of aquaculture production was 9% per year during 1970-2000, compared with only 1.3% for capture fisheries (Tacon, 2003). Half of total global aquaculture production in 2002 was finfish (25,728,61 1 Mt) [15].

Tilapia are freshwater fish belonging to the family Cichlidae. They are native to Africa, but were introduced into many tropical, subtropical and temperate regions of the world during the second half of the 20th century (Pillay, 1990). The introduction of tilapia into those areas was for: farming as food fish; recreational fishing; aquatic weed control; and research purposes. Tilapia have many attributes that make them an ideal candidate for aquaculture, especially in developing countries. These include:

- Fast Growth
- Tolerance to a wide range of environmental conditions (such as temperature, salinity, low dis- solved oxygen, etc.).
- Resistance to stress and disease.
- Ability to reproduce in captivity and short generation time.
- Feeding on low trophic levels and acceptance of artificial feeds immediately after yolk-sac absorption.

Tilapia culture is believed to have originated some 4000 years ago, about 1000 years before carp culture was introduced into China (Balarin and Hatton, 1979). However, other than biblical references and illustrations from ancient Egyptian tombs, very little information is available on their culture during those early times.

Tilapia culture during that period. Only seven countries reported tilapia production in 1950, increasing to 12 countries in 1969. Taiwan, China, Egypt, Nigeria, Israel and Thailand were the major tilapia producers. 'The insignificant contribution of tilapia production during that period was mainly because aquaculture in general, and tilapia culture in particular, was not known as a food production system in most countries.

FROM 1970 TO 1990. Tilapia culture Was gradually expanding worldwide during the period from 1970 to 1990. The number of countries practicing tilapia culture increased significantly to reach 78 countries in 1990, compared to only 12 countries in 1969. However, tilapia production in of those countries was very limited. many According to FAO aquaculture production statistics, out of those 78 countries, 40 countries produced less than 100 Mt/year each. The pro- duction of farmed tilapia gradually increased to reach 383,654 Mt by 1990, representing 2.28% of total aquaculture production in 1990. During that period, the annual growth of tilapia production fluctuated between <6% and > 28%, with an average of 14.2% [15].

1.2.1. Aquaculture historical review in Algeria

Aquaculture in Algeria has a rich and evolving history that spans several decades. The industry has undergone significant developments and milestones, shaping its current status. Algerian aquaculture has a history that dates back to the early 20th century. The establishment of the BouIsmail station in 1921 marked the inception of the national oyster industry (Crassostrea gigas) and mussel (Mytilus galloprovincialis) farming. In 1937, a freshwater fish breeding station focused on species like largemouth Bass (Micropterus salmoides) and rainbow trout (Oncorhynchus mykiss).

The aim was to stock impoundments and wadis with these fish species. However, the station was later closed. During the 1940s, efforts were made to exploit the lakes in Eastern Algeria, which encompass Mellah, Oubeira, and Tonga. This entailed the set-up of fish weirs, the initiation of both fisheries, and the cultivation of shellfish of species such as M.galloprovincialis, C. gigas, and grooved carpet shell (Ruditapesdecussatus).

In the following decades, the aquaculture industry in Algeria experienced further developments. Cooperation programs were initiated with China, focusing on carp reproduction techniques and restocking activities. Private producers also played a role in aquaculture, exporting significant produce to Italy. From 1982 to the present, the industry has seen continued growth and government support. The National Dams Agency initiated dam restocking operations, introducing species such as common carp (Cyprinus carpio), grass carp (Ctenopharyngodonidellus), Silver carp (Hypophthalmichthys molitrix), and bighead carp (Hypophthalmichthys nobilis).

The government has provided subsidies to promote and develop the aquaculture sector, establishing maritime aquaculture enterprises, freshwater aquaculture stations, and open-sea shellfish culture. Today, sea impoundment fisheries dominate aquaculture production in Algeria, with a focus on marine species such as European seabass (Dicentrarchuslabrax) and githead seabream (Sparus aurata). In addition, efforts are being made to integrate aquaculture with agriculture in Saharan zones, and the government continues to support the growth and development of the industry. Algerian aquaculture production is now in a phase of rapid expansion and development, signalling significant growth potential for the industry [6].

1.3. Global tilapia production

Tilapia aquaculture is a significant industry in several countries, with China, Indonesia, Egypt, Brazil, and Thailand being the top five producers globally. China is the largest producer, with an output of 1,241,410 tons in 2022, followed by Indonesia with 1,172,633 tons. Egypt ranks third, with a production of 954,154 tons in 2022, and is the largest tilapia producer in Africa, accounting for 90% of the continent's total aquaculture harvest [12].

Asia:

China, Indonesia, and Thailand are major producers in Asia, with China being the largest producer globally. Asian countries have a significant share of the global tilapia production, with diverse farming practices ranging from small backyard ponds to large-scale operations.

Africa:

Egypt is the largest tilapia producer in Africa, accounting for a substantial portion of the continent's aquaculture harvest.

Other African countries like Malawi, Kenya, Uganda, Tanzania, Mozambique, Namibia, Botswana, and Angola are also involved in tilapia aquaculture, albeit to varying extents.

Europe:

European tilapia production is relatively small compared to other continents due to the need for warm temperatures for rearing.

Countries like Belgium, Holland, Switzerland, Spain, Germany, France, and the United Kingdom are involved in tilapia farming, often requiring temperature-controlled environments.

Latin America:

Brazil is a key player in tilapia production in Latin America, experiencing significant growth in the industry. The region benefits from a favorable climate, abundant water resources, and a growing domestic market, driving the expansion of tilapia farming.

Americas:

Countries in the Americas, including Brazil, Colombia, Mexico, Honduras, Ecuador, Costa Rica, Guatemala, El Salvador, Paraguay, and the United States, contribute significantly to tilapia aquaculture production in the region.

The Americas have a notable share of global tilapia production, with various countries actively engaged in farming and contributing to the industry's growth [16].

Table I 1- Continental Production (Mt) of farmed tilapia during 1950-2002 [40]

Year	1950	1960	1970	1980	1990	1992	1994	1996	1998	2000	2001	2002
Africa	908	3,399	4,723	12,456	33,094	35,715	38,164	40,077	67,421	177,202	174,985	193,240
Asia	4,810	13,932	23,337	88,011	333,016	421,649	521,914	715,602	814,407	997,046	1,124,602	1,191,611
N. America	0	0	200	7,963	14,891	18,020	22,308	24,730	25,522	33,418	37,753	45,089
S. America	0	0	0	103	2,307	12,732	12,728	31,849	45,716	66,087	66,966	75,328
Oceania	0	0	0	0	105	211	221	272	393	456	398	346

1.3.1. Tilapia production in Asia

Asia is the largest tilapia producer in the world, accounting for 79% of the production of global farmed tilapia in 2002. Tilapia is farmed mainly in freshwater environment in Asia. In 2002, about 95.5% of total farmed tilapia production came from freshwater environments. 'Twenty-one Asian countries, mainly in South Asia and the Far East, reported tilapia production in 2002 [15].

Tilapia culture in Asia has witnessed three developmental phases:

1. 1950-1980: During this early period, tilapia culture was practiced very small scale and on a grew at slow rates. The production gradually increased from only 4,810 Mt in 1950 to reach 88,01 1 Mt in 1980,
2. 1981-1991: The production of tilapia witnessed a sharp increase from 109,301 Mt in 1981 to reach 353,686 Mt in 1991, with an over 300% increase.
3. 3. 1992-now: This period was characterized by an outstanding expansion and development of tilapia culture in Asia. As a result, tilapia pro- duction jumped from 421,649 Mt in 1992 to 1,191,61 1 Mt in 2002 (Table 1.3.2).

The growth rate in the production of farmed tilapia in Asia during 1950-2002 was among the fastest in world, with an overall average of 20.5% annually. It is noteworthy that the recorded production of tilapia in Asia is lower than the real production, because the production of some other Asian countries [15].

Table I 2- Production (Mt) of farmed tilapia by country in Asia during 1950-2002 [40]

Country	1950	1960	1970	1980	1990	1992	1994	1996	1998	2000	2001	2002
Brunei	...	...	...	...	1	3	3	10	20	14	...	52
Cambodia	...	...	...	...	170	230	200	230	330	370	359	376
China	660	5,003	5,828	9,000	106,071	157,233	235,940	394,303	525,926	629,182	671,666	706,585
Hong Kong	...	...	450	2,120	1,195	980	161	442	1,058	613	641	411
Indonesia	100	100	1,191	14,901	53,768	59,945	64,431	75,473	65,894	85,179	105,106	109,768
Israel	20	95	1,400	2,512	4,795	3,368	5,631	6,399	6,696	7,059	8,217	7,819
Japan	...	...	...	2,392	5,825	4,697	2,125	1,479	885	434	434	400
Jordan	...	...	...	...	40	16	67	135	263	563	540	515
Republic of Korea	...	...	...	...	650	437	448	998	796	787	609	588
Kuwait	...	...	...	...	...	...	...	...	70	30	16	16
Laos	...	...	20	176	1,250	1,345	1,400	2,000	9,549	18,928	22,499	26,872
Lebanon	...	...	...	...	...	...	...	...	...	...	...	25
Malaysia	...	< 0.5	12	366	1,145	4,632	8,507	11,177	12,625	18,471	16,253	20,757
Myanmar	...	...	...	...	...	...	...	...	...	...	...	1,000
The Philippines	...	70	1,417	13,214	76,142	91,173	90,341	79,415	72,023	92,579	106,746	122,390
Saudi Arabia	...	...	...	...	1,926	2,191	2,220	3,614	3,315	3,968	3,981	2,019
Singapore	...	...	...	...	...	...	...	45	150	37	52	142
Sri Lanka	...	...	...	1,097	4,500	3,500	2,500	2,500	3,500	4,390	3,130	3,670
Syria	...	...	...	102	596	1,126	991	1,588	1,372	2,626	3,195	2,571
Taiwan	3,900	8,200	11,287	33,712	52,047	47,226	47,435	44,756	36,126	49,235	82,781	85,059
Thailand	130	464	1,732	8,419	22,895	43,547	59,514	91,038	73,809	82,581	98,377	100,576
Total	4,810	13,932	23,337	88,011	333,016	421,649	521,914	715,602	814,407	997,046	1,124,602	1,191,611

1.3.2. Tilapia production in Africa

Despite the fact that tilapia are African fish, tilapia culture in Africa is relatively new, with a low contribution to world tilapia production, being 12.8% in 2002. Farmed tilapia production in Africa, however, has sharply increased during the past few years (Table 1.3.2). Generally, the trend in tilapia production in Africa can be divided into three phases: 1. 1950–1984: During this 35-year period, the production of tilapia slowly grew from 908 Mt in 1950 to 15,747 Mt in 1984. 2. 1985–1997: Production jumped from 15,747 Mt in 1984 to 28,724 Mt in 1985, and continued to grow at a relatively slow rate to reach 43,946 Mt in 1997. 3. 1998–now: Tilapia production increased from 43,946 Mt in 1997 to 67,421 Mt in 1998, with an increase in growth rate of 53.4%. Another huge increase in tilapia production occurred during 1999–2002, with 119,416, 177,202, 174,985 and 193,240 Mt produced in 1999, 2000, 2001 and 2002, respectively. The average annual growth of tilapia production during the period 1998–2002 was 47.3%, excluding the year 2001, which showed a slight decrease compared to 2000, or 37.6% if the production of the year 2001 is included.

In 2001, 32 African countries reported production of farmed tilapia; however, in 2002, some of these countries reported no production. Unlike Asia, most of farmed tilapia production in Africa comes from brackish-water environments. In 2002, tilapia production from brackish water amounted to 138,923 Mt, representing 71.9% of total African tilapia production. Farmed tilapia output in Africa is dominated by a single country: Egypt (Table 1.5). The production of farmed tilapia in Egypt accounted for 86.8% (167,735 Mt) of total production of tilapia in Africa in 2002. If the contribution of Egypt is discounted, Africa's contribution to global tilapia output would decline from 12.8% to only 1.7%. Tilapia culture in Egypt is practised mainly in brackish-water environments in the northern lakes areas along the Mediterranean coast. In 2002, the production of tilapia from brackish-water systems in Egypt reached 138,456 Mt representing 82.5% of total tilapia production in the continent. Tilapia culture is also practised in some other countries, including Nigeria, Ghana, Zambia, the Democratic Republic of Congo and Zimbabwe (Table 1.5). The contribution by the rest of African countries is insignificant [15].

Table I 3- Production (Mt) of farmed tilapia by country in Africa during 1950–2002 [40]

Country	1950	1960	1970	1980	1990	1992	1994	1996	1998	2000	2001	2002
Burkina Faso	. . .	. . .	. . .	. . .	3	2	< 0.5	30	40	5	5	5
Burundi	. . .	. . .	. . .	. . .	30	50	55	50	55	100	100	100
Cameroon	. . .	. . .	. . .	25	80	50	45	50	60	40	100	210
Republic of Central Africa	. . .	. . .	. . .	76	100	337	250	140	80	120	125	. . .
Democratic Republic of Congo	. . .	. . .	. . .	. . .	700	730	650	600	1,833	2,073	2,738	2,959
Republic of Congo	. . .	. . .	. . .	. . .	240	191	121	106	140	200	200	. . .
Côte d'Ivoire	. . .	. . .	. . .	. . .	32	44	109	933	495	967	870	725
Egypt	700	2,100	2,500	9,000	24,916	21,505	25,214	27,854	52,755	157,425	152,515	167,735
Ethiopia	. . .	. . .	. . .	. . .	30	20	30	35	10	< 0.5	< 0.5	. . .
Gabon	. . .	. . .	. . .	. . .	2	5	23	59	150	533	102	83
Ghana	. . .	. . .	94	251	280	300	330	350	1,350	3,712	4,400	4,400
Guinea	. . .	. . .	. . .	. . .	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	. . .
Kenya	. . .	. . .	. . .	70	405	467	502	500	87	222	412	421
Liberia	. . .	. . .	. . .	. . .	< 0.5	< 0.5	< 0.5	< 0.5	. . .	19	12	12
Madagascar	. . .	. . .	. . .	. . .	40	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Malawi	. . .	. . .	. . .	30	50	30	28	20	22	500	532	620
Mali	. . .	. . .	. . .	. . .	10	20	58	35	35	19	350	708
Mauritius	. . .	. . .	. . .	. . .	8	12	32	71	40	44	30	20
Mayotte	. . .	. . .	. . .	. . .	. . .	. . .	. . .	1	2	3	3	. . .
Mozambique	. . .	. . .	. . .	. . .	15	12	116	4	< 0.5	< 0.5	< 0.5	77
Niger	. . .	. . .	. . .	. . .	36	8	17	11	12	15	21	40
												Continued
Nigeria	208	1,299	2,129	2,952	3,795	7,525	5,500	3,259	4,471	2,705	2,626	4,496
Rwanda	. . .	. . .	. . .	23	154	45	50	90	120	252	381	542
Réunion	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	75	88	68	60
Senegal	. . .	. . .	. . .	. . .	5	5	31	53	3	9	10	22
Sierra Leone	. . .	. . .	. . .	2	20	20	25	30	30	30	30	. . .
South Africa	. . .	. . .	. . .	. . .	30	55	60	15	70	110	200	200
Sudan	. . .	. . .	. . .	. . .	234	200	200	1,000	1,000	1,000	1,000	1,000
Swaziland	. . .	. . .	. . .	. . .	. . .	. . .	. . .	47	49	38	40	. . .
Tanzania	. . .	. . .	. . .	. . .	375	350	150	200	200	210	300	630
Togo	. . .	. . .	. . .	. . .	22	150	150	21	25	102	120	25
Uganda	. . .	. . .	. . .	. . .	32	42	108	40	200	600	1,550	1,957
Zambia	. . .	. . .	. . .	27	1,400	3,500	4,280	4,403	3,942	4,020	3,980	3,980
Zimbabwe	. . .	. . .	. . .	. . .	50	40	30	70	70	2,041	2,165	2,213
Total	908	3,399	4,723	12,456	33,094	35,715	38,164	40,077	67,421	177,202	174,985	193,240

1.3.3. Tilapia production in South America

Tilapia culture is relatively new in South America. It started on a small scale, mainly for subsistence farming, in the early 1970s. The first FAO record of tilapia production in the region was reported in Colombia in 1971, with only 1 Mt of Nile tilapia. The progress of tilapia culture in South America can be divided into three phases: 1. 1971–1982: During this period, tilapia culture was practised in only two countries, Colombia and Peru, with very little production, ranging from 1 Mt in 1971 to 182 Mt in 1982. 2. 1983–1991: During this period, the number of countries practising tilapia culture increased gradually to six countries in 1991. Nevertheless, tilapia production was still very low and was dominated by one country: Colombia (87.5%). 3. 1992–now: The production of cultured tilapia in South America increased from 3475 Mt in 1991 to 12,732 Mt in 1992, with a 266% increase. Another jump occurred in 1995, where the production approached 30,032 Mt, with a 136% increase. The production continued to increase at a high rate, to reach 75,328 Mt in 2002, which represented 5% of global production of farmed tilapia. Consequently, the number of countries practising tilapia culture increased to ten (Table 1.7). The average annual growth rate of tilapia production during 1996–2002 was 15.7%. More than 99% of tilapia production comes from freshwater environments.

As mentioned earlier, Colombia was the only country practising tilapia culture in South America in the 1970s, while Peru reported tilapia production starting 1979. In 1980, total production of tilapia was only 103 Mt but increased to 2307 Mt in 1990. In 2002, ten countries reported tilapia production. Interestingly, the first record of tilapia production in Brazil appeared in 1995. During 1995–2002, tilapia production in that country increased from 12,014 Mt to 42,003 Mt. This means that Brazil has one of the fastest growth rates of tilapia production in South America, with an average annual growth rate of 20%. As a result, Brazil contributed 55.8% (42,003 Mt) to tilapia production in the continent in 2002. Departing from the FAO tilapia production statistics, Kubitza (2004) reported that farm-raised tilapia in Brazil reached 57,000 Mt in 2002. Moreover, he stated that, at present, production is estimated at about 70,000 Mt. Colombia and Ecuador are the second and third major tilapia producers, with a production amounting to 24,000 Mt (31.9%) and 8181 Mt (10.9%) in 2002. Brazil, Colombia and Ecuador accounted for 98.5% of

total tilapia production in 2002. This means that the current production of tilapia in the other South American countries is not significant.

Tilapia production in South America is reported in the 'unidentified' category. Out of the 75,328 Mt of tilapia produced in 2002, 62,723 Mt were 'unidentified' tilapias (83.3%). Nile tilapia is the second most important cultured category, where it accounted for 16.5% (12,422 Mt) of total tilapia production in 2002. Other tilapia/cichlids, including Cichlasoma, green terror (Aequidens rivulatus), Mozambique tilapia, redbreast tilapia and velvety cichlids are also cultured in South America, but on a very small scale, with negligible production. The culture of Cichlasoma stopped completely after 1993, while that of green terror, redbreast tilapia and velvety tilapia stopped in the late 1990s [15].

Table I 4- Production (Mt) of farmed tilapia by country in South America during 1980–2002 [40].

Country	1980	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Brazil	. . .	. . .	. . .	. . .	. . .	. . .	12,014	15,700	16,845	24,062	27,104	32,459	35,830	42,003
Colombia	93	2,040	3,040	11,050	11,046	11,084	16,057	14,026	16,112	17,665	19,842	22,870	24,000	24,000
Ecuador	. . .	21	33	876	912	68	< 0.5	< 0.5	1,730	1,730	4,400	9,201	5,169	8,181
Venezuela	. . .	4	127	400	700	1,103	1,650	1,700	1,936	2,010	2,320	970	1,250	560
Guyana	. . .	30	50	75	100	159	160	160	170	180	369	369	370	370
Peru	10	186	200	250	181	205	< 0.5	47	< 0.5	. . .	. . .	8	223	122
Suriname	. . .	. . .	. . .	. . .	. . .	1	1	1	1	1	50	130	54	54
Bolivia	. . .	. . .	. . .	51	79	68	70	55	40	30	30	30	30	35
Paraguay	. . .	26	25	30	30	40	80	150	210	38	38	40	40	. . .
Argentina	. . .	. . .	. . .	. . .	. . .	. . .	. . .	10	10	. . .	. . .	10	. . .	3
Total	103	2,307	3,475	12,732	13,048	12,728	30,032	31,849	37,054	45,716	54,153	66,087	66,966	75,328

. . . denotes that data are not available, unobtainable or not separately available but included in another category.

1.3.4. Tilapia production in North America

Mozambique tilapia were introduced into the Caribbean in 1947 and first came to the USA in 1954 (Fitzsimmons, 2001a). Tilapia culture in North America and the Caribbean is therefore relatively new, beginning in the 1960s and 1970s, on a small scale, mainly for subsistence objectives. The first FAO record of tilapia production appeared in 1970, with 200 Mt from Mexico. During 1984–2002, the production increased progressively at an annual growth rate of 12.75%, to reach 45,089 Mt in 2002 (Table 1.9), which represented about 3% of global tilapia production. More than 99% of tilapia production in North America and the Caribbean comes from freshwater environments.

Twenty countries from North America and the Caribbean reported tilapia production in 2002. Unlike Asia, Africa and South America, where a single country in each continent dominates tilapia production, no single country dominates the production in North America and the Caribbean (Table 1.9). Instead, Costa Rica, the USA, Mexico and Jamaica together accounted for 78.7% of tilapia production in 2002 (29.3%, 20%, 16.1% and 13.3%, respectively). Countries such as the Dominican Republic, Guatemala, Honduras, Panama, Cuba and El Salvador are also paying considerable attention to tilapia culture. The production of the rest of North American countries is not significant [15].

Table I 5- Production (Mt) of farmed tilapia by country in North America and the Caribbean during 1970–2002 [40]

Country	1970	1980	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Costa Rica	...	18	232	1,200	1,350	2,360	2,790	3,800	4,100	4,100	5,398	6,588	8,100	8,500	13,190
Cuba	...	1,012	3,733	3,313	3,425	2,337	2,363	2,096	2,418	1,888	540	1,060	730	480	500
Dominican Republic	...	...	100	374	400	218	1,311	985	177	344	446	445	994	1,666	2,084
El Salvador	...	...	4	17	36	105	151	196	93	138	278	141	56	29	405
Guatemala	...	...	161	201	540	486	638	774	1,751	2,074	1,647	3,352	2,361	2,501	2,501
Honduras	...	6	120	119	173	184	102	172	190	232	102	135	927	1,900	2,874
Jamaica	...	20	3,364	3,100	3,200	3,300	3,400	3,500	3,450	3,400	3,360	4,100	4,500	4,500	6,000
Martinique	...	...	36	35	50	62	65	30	13	10	10	10	8	8	8
Mexico	200	6,907	5,000	4,500	4,600	4,800	5,439	1,482	4,800	8,318	5,398	7,023	6,726	8,845	7,271
Nicaragua	...	...	3	4	4	4	4	5	52	45	15	16	24	64	64
Panama	...	...	49	83	65	77	109	186	115	102	55	634	900	1,181	1,181
Puerto Rico	...	...	3	164	85	48	43	48	24	6	6	3	15	18	3
Trinidad and Tobago	...	...	2	3	3	4	4	15	15	13	13	12	21	6	6
USA	...	...	2,041	2,041	4,082	5,670	5,888	6,838	7,242	7,648	8,251	8,051	8,051	8,051	9,000
Total	200	7,963	14,891	15,158	18,020	19,657	22,308	20,143	24,730	28,458	25,522	31,573	33,418	37,753	45,089

1.4. Current Situation of Aquaculture in Algeria

Aquaculture in Algeria encompasses various aspects:

1. In the eastern part of the country, fisheries within brackish and freshwater lake basins contribute to a diverse array of fish species. These species encompass mullet, eels, sole, European bass, common carp, gilthead seabream, sand steenbras, clams, oysters, caramote prawns, white seabream, and Chinese carp. Inland impoundments play a significant role in supporting aquaculture production. They are utilized to cultivate

common carp, Chinese carp, tilapia, barbel species, shrimps, and other crustacean species such as crayfish (R. Bilal, pers. comm. 2023), contributing to developing inland commercial fisheries.

2. Private operators engage in marine fish farming by using floating cages. This method produces species of European seabass, Meagre, and gilthead seabream. The reproduction of these two species takes place at the sole marine farm in the region under the supervision of the National Center for Research and Development in Fisheries and Aquaculture (CNRDPA).

3. Shellfish culture is also conducted by private business operators, leading to the production of significant quantities of Mediterranean mussels and Pacific-cupped oysters. These diverse aquaculture practices showcase the efforts to enhance its domestic aquaculture production and contribute to the sustainable development of the fisheries and aquaculture industry.

1.4.1 Aquaculture Production in Algeria

Aquafarming in Algeria has shown significant growth and fluctuations over the years. From around 450 tonnes two decades ago, it expanded to 4,779.29 tonnes in 2021, with a value of USD 20.733 thousand. Nonetheless, Aquatic farming in the country remains relatively low compared to the top 10 African countries, constituting just 0.21% of the total aquaculture production on the continent [6].

Despite this, Algeria has experienced a relatively high annual growth rate of 12.49%, surpassing sub-regional, regional, and global averages. Except for Tunisia, it also has the highest growth rate among its neighbouring countries.

The production volume from commercial farming has been modest and highly variable. Over the years, aquaculture production in Algeria has witnessed fluctuations. It decreased from 407 tonnes in 1990 to 368 tonnes in 2005, then surged to 2,779.91 tonnes in 2008. However, there

was a significant decrease to 1,759 tonnes in 2010, followed by a further decline to 1,332 tonnes in 2015. The production then experienced a jump to 5,436 tonnes in 2020 but decreased again to 4,779.29 tonnes in 2021. Despite these fluctuations, there has been a steady increase in the portion of aquaculture in the total fisheries production of Algeria. It has grown from less than 05% before 2005 to nearly 6% in 2021 [6].

Table I 6- Status and trends of aquaculture production, 2001-2021 [40]

Country/area	Aquaculture production of total species (tonnes)		Annual growth (%)
	2001	2021	
World	34617654.72	90863706.34	4.94
Africa	405675	2322023.3	9.11
Northern Africa	348629	1638558.1	8.05
Algeria and selected neighbouring countries			
Egypt	342864	1576189.4	7.93
Spain	311591	279880.43	-0.54
Italy	218330	145861.9	-2.00
France	251620	198505.7	-1.18
France	251620	198505.7	-1.18
Greece	97512	143863.47	1.96
Türkiye	67244	471686	10.23
Tunisia	1868	25957.2	14.06
Morocco	1403	1922.18	1.59
Sudan	1000	9900	12.15
Algeria	**454**	**4779.29**	**12.49**

1.5. Tilapia farming principles

Tilapia are a popular choice for aquaculture due to their fast growth rate and ease of management. However, to ensure their health and optimal yields, farmers need to provide for their fundamental requirements. These factors form a "thriving triangle" for tilapia, where each element plays a crucial role in their well-being and successful production.

1.5.1. Physical characteristics

Tilapia are shaped much like sunfish or crappie but can be easily identified by an interrupted lateral line characteristic of the Cichlid family of fishes. They are laterally compressed

and deep-bodied with long dorsal fins. The forward portion of the dorsal fin is heavily spined. Spines are also found in the pelvis and anal fins. There are usually wide vertical bars down the sides of fry, fingerlings, and sometimes adults [14].

1.5.2. Feeding behavior and nutrition requirements

Tilapia ingest a wide variety of natural food organisms [14], including plankton, some aquatic macrophytes, planktonic and benthic aquatic invertebrates, larval fish, detritus, and decomposing organic matter. With heavy supplemental feeding, natural food organisms typically account for 30 to 50 percent of tilapia growth. (In supplementally fed channel catfish only 5 to 10 percent of growth can be traced to ingestion of natural food organisms.)

Tilapia are often considered filter feeders because they can efficiently harvest plankton from the water. However, tilapia do not physically filter the water through gill rakers as efficiently as true filter feeders such as gizzard shad and silver carp. The gills of tilapia secrete a mucous that traps plankton. The plankton-rich mucous, or bolus, is then swallowed. Digestion and assimilation of plant material occurs along the length of the intestine (usually at least six times the total length of the fish). The Mozambique tilapia is less efficient than the Nile or Blue tilapia at harvesting planktonic algae. Two mechanisms help tilapia digest filamentous and planktonic algae and succulent higher plants: 1) physical grinding of plant tissues between two pharyngeal plates of fine teeth; and 2) a stomach pH below 2, which ruptures the cell walls of algae and bacteria [14].

The commonly cultured tilapias digest 30 to 60 percent of the protein in algae; blue-green algae is digested more efficiently than green algae. When feeding, tilapias do not disturb the pond bottom as aggressively as common carp. However, they effectively browse on live benthic invertebrates and bacteria-laden detritus. Tilapias also feed on midwater invertebrates. They are not generally considered piscivorous, but juveniles do consume larval fish. In general, tilapias use natural food so efficiently that crops of more than 2,700 pounds of fish per acre (3,000 kg/ha) can be sustained in well-fertilized ponds without supplemental feed. The nutritional value of the natural food supply in ponds is important, even for commercial operations that feed fish

intensively. In heavily fed ponds with little or no water exchange, natural food organisms may provide one-third or more of total nutrients for growth. In general, tilapia digest animal protein in feeds with an efficiency similar to that of channel catfish, but are more efficient in the digestion of plant protein, especially more fibrous materials.

Tilapia require the same ten essential amino acids as other warmwater fish, and, as far as has been investigated, the requirements for each amino acid are similar to those of other fish. Protein requirements for maximum growth are a function of protein quality and fish size and have been reported as high as 50 percent of the diet for small fingerlings. However, in commercial food fish ponds the crude protein content of feeds is usually 26 to 30 percent [14], one tenth or less of which is of animal origin. The protein content and proportion of animal protein may be slightly higher in recirculating and flow-through systems. The digestible energy requirements for economically optimum growth are similar to those for catfish and have been estimated at 8.2 to 9.4 kcal DE (digestible energy) per gram of dietary protein. Tilapia may have a dietary requirement for fatty acids of the linoleic (n-6) family.

Tilapia appear to have similar vitamin requirements as other warmwater fish species. Vitamin and mineral premixes similar to those added to catfish diets are usually incorporated in commercial tilapia feeds. The feeding behavior of tilapia allows them to use a mash (unpolluted feeds) more efficiently than do catfish or trout, but most commercial tilapia feeds are pelletized to reduce nutrient loss. In the absence of feeds specifically prepared for tilapia, a commercial catfish feed with a crude protein content of 28 to 32 percent is appropriate in the United States [14].

1.5.3. Environmental requirements

Tilapia are more tolerant than most commonly farmed freshwater fish to high salinity, high water temperature, low dissolved oxygen, and high ammonia concentrations.

a. Salinity

All tilapia species are tolerant to brackish water. The Nile tilapia is the least saline tolerant of the commercially important species, but grows well at salinities up to 15 ppt. The Blue tilapia grows well in brackish water up to 20 ppt salinity, and the Mozambique tilapia grows well at salinities near or at full strength seawater. Therefore, the Mozambique tilapia and some mossambicusderived “red” tilapia are preferred for saltwater culture. Some lines of the Mozambique tilapia reportedly have spawned in full strength seawater, but its reproductive performance begins to decline at salinities above 10 to 15 ppt.

The Blue and Nile tilapias can reproduce in salinities up to 10 to 15 ppt, but perform better at salinities below 5 ppt. Fry numbers decline substantially at 10 ppt salinity [14].

b. Water temperature

The intolerance of tilapia to low temperatures is a serious constraint for commercial culture in temperate regions. The lower lethal temperature for most species is 50 to 52o F for a few days [14], but the blue tilapia tolerates temperatures to about 48o F. Tilapia generally stop feeding when water temperature falls below 63o F. Disease-induced mortality after handling seriously constrains sampling, harvest and transport below 65o F. Reproduction is best at water temperatures higher than 80o F and does not occur below 68o F. In subtropical regions with a cool season, the number of fries produced will decrease when daily water temperature averages less than 75o F. After 16- to 20- day spawning cycles with 1/2-pound Nile tilapia, fry recovery was about 600 fry per female brooder at a water temperature of 82o F, but only 250 fry per female at 75o F. Optimal water temperature for tilapia growth is about 85 to 88o F. Growth at this optimal temperature is typically three times greater than at 72o F [14].

c. Dissolved oxygen concentration

Dissolved oxygen (DO) is one of the limiting environmental factors affecting fish feeding, growth and metabolism. DO fluctuation is affected by photosynthesis, respiration and diel fluctuation. These factors must be fully considered where DO is concerned. Ambient DO range produces the best fish performance, while low DO levels limit respiration, growth and other metabolic activities of fish (Tsadik and Kutty, 1987). Tilapia are known to withstand very low

levels of DO. Most tilapias can tolerate DO levels as low as 0.1–0.5 mg/l for varying periods of time (Magid and Babiker, 1975; Tsadik and Kutty, 1987). They can even survive at zero DO concentration, if they are allowed access to surface air. But tilapia usually suffer from high mortality if they fail to reach surface air. On the other hand, tilapia can tolerate conditions of high oxygen supersaturation (up to 400%), which usually occurs because of high photosynthesis resulting from phytoplankton and macrophytes blooming (Morgan, 1972). It is well known that increasing water temperature reduces the rate of DO in the water.

This leads to increased respiration rate and oxygen consumption in tilapia, because under increased water temperature the rate of metabolism and, in turn, the tissue demand for oxygen increases. Franklin et al. (1995) found that the rate of oxygen consumption in tilapia increased from 0.74 to 0.97 mg/l/h with increasing water temperature from 37 to 42°C. Similar results were reported with a number of tilapia species and their hybrids (Becker and Fishelson, 1986). Moreover, early studies of Job (1969a, b) indicated that the respiration of tilapia was independent of DO at oxygen saturation of 25–32% (at temperature ranging from 15 to 30°C), while below these saturation levels the metabolic rate became dependent on oxygen availability, and mortality occurred when DO remained below 20% saturation for more than 2–3 days. On the contrary, Teichert Coddington and Green (1993) found that reducing the aeration in tilapia ponds in Honduras from 30% to 10% of oxygen saturation did not affect fish growth and water quality, and both aeration levels produced better growth than unaerated ponds.

Nevertheless, the authors reported that aeration leads to the suspension of settled particulate matter and causes water turbidity and suggested that more research is needed to improve aeration techniques in order to reduce such turbidity. Handling stress has a significant effect on oxygen consumption in tilapia. Ross and Ross (1983) found that handling stress in Nile tilapia increased oxygen consumption rate from +150% to +300% of the resting value, and did not fully return, in many cases, to the resting value after 3 h. The authors suggested that, following handling stress, the fish should be returned to water containing high levels of DO and should not be fed for at least 1 h. The message from this result is clear: ‘handling stress should be minimized’. The respiration rate of the fish also increased curvilinearly with increasing body weight. Although tilapia can survive acute low DO concentrations for several hours, tilapia ponds should be managed to

maintain DO concentrations above 1 mg/L. Metabol-ism, growth and, possibly, disease resistance are depressed when DO falls below this level for prolonged periods.

Increases in carbon dioxide tension in the water lead to decreased oxygen consumption (but increased ventilation rate). However, in addition to their tolerance of low levels of DO, tilapia can also withstand very high levels of CO2, ranging from 50 to 72.6 ppm (Fish, 1956). It has been suggested that high CO2 water supplies caused nephrocalcinosis in tilapia (R.J. Roberts, cited in Chervinski, 1982). This means that CO2 concentration should also be kept minimal in tilapia culture water [14].

d. pH range in water

Some tilapias are known to tolerate a very wide range of water pH. For example, the tilapia Oreochromis alcalicus grahami live successfully in Lake Magadi (Kenya), which has a pH of 10.5 (Randall et al., 1989). These fish were reported to tolerate a pH range of 5 to 11 for at least 24 h, but they die at pH < 3.5 and > 12 (Reite et al., 1974). They overcome the problem of ammonia excretion by excreting about 90% of their nitrogenous wastes as urea. This process is facilitated by seawater-type gill chloride cells (Wilkie and Wood, 1996). Nile tilapia can also survive at a pH range of 4–11 (Balarin and Hatton, 1979; Wangead et al., 1988). In the meantime, Tilapia congica live in the very acidic water (4.5–5.0) of Lake Tumba (Zaire). Wangead et al. (1988) studied the effects of acid water on the survival, behaviour and growth of Nile tilapia fingerlings (0.4–1.0 g) and adults (45.4–46.3 g). They found that both fingerlings and adults died at pH 2–3 within 1–3 days. Both size groups tolerated pH 4–5 very successfully, and attained survival and growth rates similar to the control group (pH 7) after 60–70 days.

However, adult fish were more resistant to low pH, with a survival rate of 86.6, 100 and 100% at pH 4, 5 and 7, respectively, whereas the survival of fingerlings was 57.8, 82.2 and 84.5%, respectively, at the same pH values. Other tilapias are less tolerant to water pH and may develop physiological changes following transfer from neutral water to acidic water. Yada and Ito (1997) studied the effects of transferring O. niloticus and O. mossambicus from neutral water to acidic water with a pH of 4.5, 4.0 and 3.5. After 3 days, O. niloticus showed the lowest level of plasma

Na+ at a pH below 4.5, while the lowest level of plasma Na+ in O. mossambicus occurred only at pH 3.5. Plasma Na+ of O. mossambicus tended to get back to normal, while that of O. niloticus continued to decrease after the exposure to pH 3.5. In both species, gill Na+, K+ ATPase activity increased after the exposure to acidic water. These results indicated that O. mossambicus have a greater ability to maintain plasma Na+ in acidic water than O. niloticus. On the other hand, low or high water pH may lead to behavioural changes, damage of gill epithelial cells, reduction in the efficiency of nitrogenous excretion and increased mortality.

In support, Wangead et al. (1988) reported that fingerling and adult Nile tilapia exposed to pH 2–3 showed rapid swimming and opercular movements, surfacing and gulping of air, lack of body position and mass mortality within 1–3 days. Similarly, Chen et al. (2001) found that O. mossambicus exposed to high pH for 7 days decreased ammonia nitrogen excretion, but increased urea nitrogen excretion. This situation was reversed at low pH (i.e. increased ammonia excretion and decreased urea excretion). The authors also reported that the median lethal dissolved oxygen (LDO50) increased significantly at low pH (7.14, 4.02, 3.36, 0.84 and 0.32 mg/l at pH 4, 5, 6, 8.3 and 9.6, respectively).

Bonga et al. (1987) found that the short-term effects of acid exposure on prolactin secretion in O. mossambicus depend on pH and rate of acidification. Rapid acidification to pH 4 resulted in necrosis of the integumental epithelium and caused damage of the skin and high plasma electrolyte loss and impaired the response of prolactin cells. At a lower acidification rate (0.5 pH units/min), these symptoms hardly occurred and branchial permeability to water and ions increased and prolactin secretion increased threefold. Slow acclimatization of tilapia to low pH may enable the fish to withstand long-term exposure to low environmental pH and prevent epithelial cell damage. Van Ginneken et al. (1997) exposed O. mossambicus to water gradually acidified to pH 4 for 37 days. The fish successfully withstood this low pH without any mortality or significant changes in energy rich compounds and plasma Na+, Cl– , cortisol and glucose between the control and acidified groups. This result indicated that the fish were able to maintain ionic balance and there was no activation in the pituitary–interrenal axis. The effects of gradual acidification on metabolic rates of O. mossambicus and common carp (Cyprinus carpio) have also been investigated by Van Dijk et al. (1993). They found that standard metabolic rate, maximum metabolic rate and oxygen

consumption in tilapia decreased in acidic water (pH 4), whereas these metabolic parameters did not decrease in carp. Wokoma and Marioghae (1996) also studied the median lethal time (LT50) and physiological changes in Tilapia guineensis in relation to varying water pH. They found that LT50 increased from 1.2 h to 62 h with the pH increasing from 2 to 3, while the critical lethal pH was 3.3. They also found that the routine metabolic rate of small fish (1.4 g) was higher than that of larger fish (10.6 g) at high ambient oxygen concentration (6.3 mg/l) and the metabolic rate decreased at low ambient oxygen concentration [15].

e. Ammonia

Massive mortality of tilapia occurs within a few days when fish are suddenly transferred to water with unionized ammonia concentrations greater than 2 mg/L. However, when gradually acclimated to sublethal levels, approximately half the fish will survive 3 or 4 days at unionized ammonia concentrations as high as 3 mg/L. Prolonged exposure (several weeks) to un-ionized ammonia concentration greater than 1 mg/L causes losses, especially among fry and juveniles in water with low DO concentration. The first mortalities from prolonged exposure may begin at concentrations as low as 0.2 mg/L. Un-ionized ammonia begins to depress food consumption at concentrations as low as 0.08 mg/L [14].

f. Nitrite

Nitrite is toxic to many fish because it makes the hemoglobin less capable of transporting oxygen; chloride ions reduce the toxicity. Tilapia are more tolerant of nitrite than many cultured freshwater fish. When dissolved oxygen concentration was high (6 mg/L) and chloride concentration was low (22 mg/L) [14], the nitrite concentration at which 50 percent of the fish died in 4 days was 89 mg/L as nitrite. In general, for freshwater culture the nitrite concentration should be kept below 27 mg/L as nitrite. As a safeguard against nitrite toxicity in recirculating systems, chloride concentrations are often maintained at 100 to 150 mg/L chloride.

1.6. Electronics contribution in Aquaculture

Aquaculture has witnessed a technological revolution in the recent years as it had to include technological solutions in order to contribute in sustainability of tilapia farms, the rapidly increased advancement in Electronics and digital technologies had a positive impact on AC as it enabled more precision in fish farming techniques with the help of sensor devices that provided RT monitoring, IoT systems that allowed remote tracking and AI powered analytics to boost productivity and reduce disease outbreaks. The adoption of these technologies opened doors for new era of precise, productive and sustainable fish farming than ever before.

Currently, only a few businesses in the industry are applying technology in their business. However, in just a few more years, the following technology trends are prospects that are likely to disrupt the face of the industry [28].

1.6.1. Sensor device helps monitor and predict environmental change

The need to monitor and respond to the effects of environmental changes – such as water temperature, pH, acidity, etc. leads to the inventions of equipment and systems that can measure store and analyze data. With such data, the managers gain an overview of real-time farming condition to take timely actions. These devices will automatically detect dispersal of algae, oil spills, over-proliferation of compounds, etc. and alert the regulators immediately.

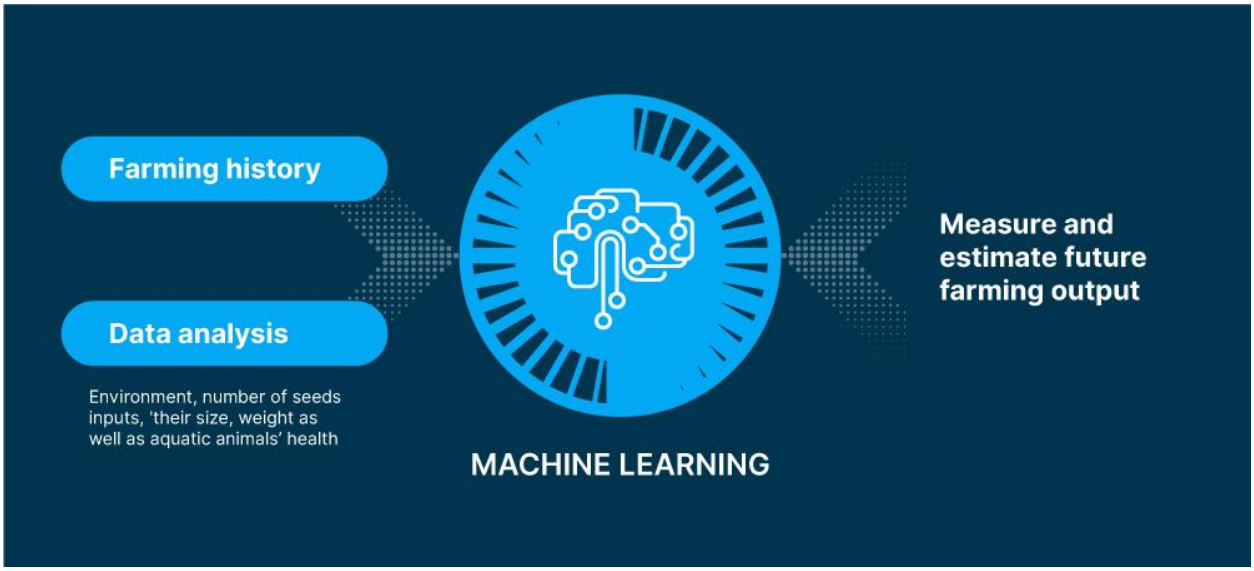


Figure I 2- Sensor devices connect with data storage systems and machine learning to analyze data and predict production

In addition, based on farming history, analyses of environment and number of seeds inputs, size, weight as well as aquatic animals' health, the system uses machine learning to measure and estimate future farming output, helping businesses in making the right business decisions and avoiding oversupply or shortage of supply.

In Japan, Umitron – a company specializing in supplying aquaculture equipment, has launched Umitron Cell, a machine that can automatically feed and control aquatic animals' weight by sensor, monitored by camera 24h/7 days using solar energy and abled to connect to smartphones and desktops. Cell also uses artificial intelligence to calculate diets and inform farmers whether the animals are full or hungry.

1.6.2. Drones help supervise offshore aquaculture

Drones have been widely used in agriculture to automatically seed and spray pesticides. In the aquaculture industry, drones are expected to be used in monitoring offshore ponds, both above and below water. Drones can replace a lot of human work such as diving to check the condition of the environment.

Apium Swam Robotics (Canada) has successfully researched and applied drones to test and analyze seawater environment through sensors. Blueye Pioneer (Norway) has launched a device to record and transmit live video underwater, which can be viewed via apps on smartphones and tablets.

1.6.3. IoT connects all devices for remote monitor

The IoT system used in aquaculture is built based on information collecting from remote sensor networks, meteorological stations, water quality control stations, on-site monitoring centers and processed on cloud platform.

Information from sensor and satellite devices measuring and monitoring will be uploaded to the cloud so that managers can track the farming process through devices such as smartwatches, smartphones or tablets.

Many farming monitoring systems such as iQShrimp (Cargill), Pondguard (Eruvaka), Aqua Spark (xPert Sea), etc. were invented based on IoT, machine learning and sensor devices.

1.6.4. Hyperspectral camera controls input/output quality

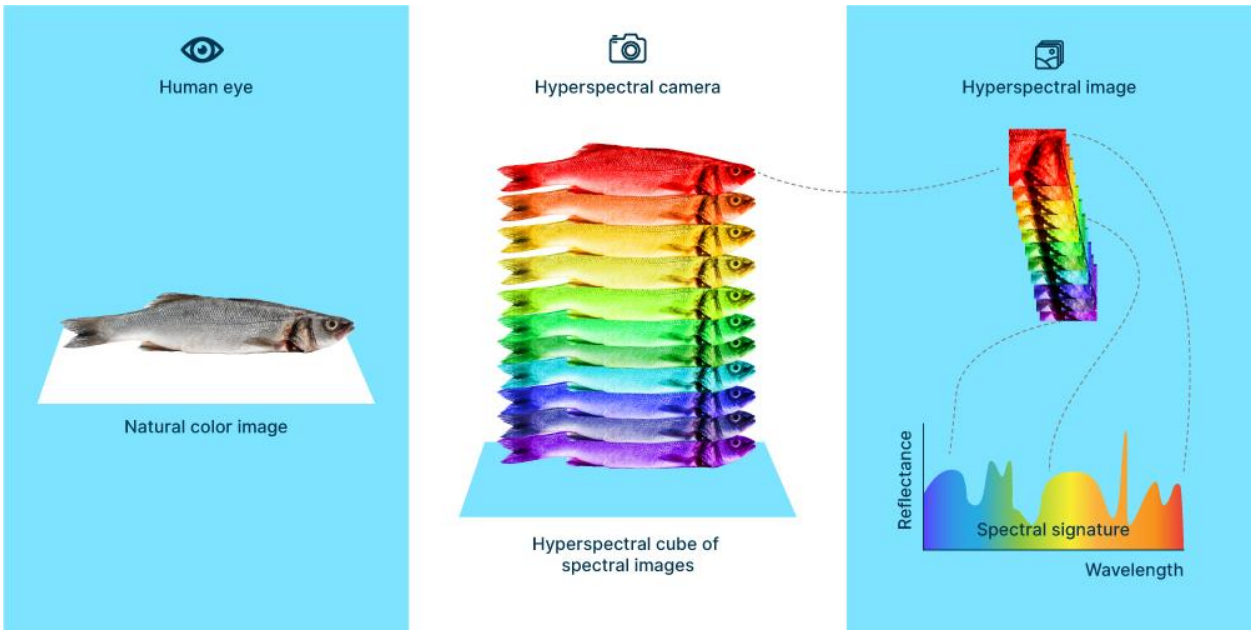


Figure I 3- Apply hyperspectral camera to control the quality of input and output

NIRS technology, near-infrared absorption spectroscopy is currently being researched and applied in quality control of some foods such as apples, bread, cereals, etc. This method of quality control is time-saving and does not invade the objects. NIRS devices will use spectral light to scan the samples, then give real-time information about the content of the substance, thereby helping to optimize product classification process.

In aquaculture, this technology is a prospect that would completely replace manual testing methods in the future.

1.7. Factors Affecting Water Quality in Aquaculture

1.7.1.1. Temperature: Maintaining Optimal Range is Critical

Temperature is a critical parameter in aquaculture that affects the growth, reproduction, and overall health of fish. According to research by the University of Arkansas, temperature fluctuations can cause stress and disease in fish, leading to increased mortality and reduced growth rates. It is essential to maintain a stable temperature that is optimal for the specific cultivated species. Different fish species have different temperature requirements. For example, Tilapia grows best at temperatures between 25°C and 32°C, while Trout prefers cooler water between 10°C and 15°C. Fluctuations in water temperature can cause stress and disease in fish, and extreme temperatures can lead to mortality [5].

1.7.1.2. pH: Maintaining the Ideal Range Prevents Stress and Disease

Maintaining optimal pH levels in aquaculture is essential for preventing stress and disease in fish and improving production. Fish are sensitive to changes in pH, which can affect their growth, reproduction, and overall health. According to the World Aquaculture Society, the recommended pH range for most freshwater fish is between 6.5 and 8.5.The pH of water is a measure of its acidity or alkalinity. Most fish species prefer a pH range of 6.5-8.5, with some species having a narrower range. Deviations from this range can cause stress and disease in fish. For example, low pH can cause acidosis and impair fish growth, while high pH can cause alkalosis and respiratory distress. Therefore, maintaining the ideal pH range is essential for the health and growth of aquatic organisms[5].

1.7.1.3. Dissolved Oxygen: Low Levels Can Be Fatal

Fish and other aquatic organisms require oxygen to breathe, and dissolved oxygen (DO) is a critical water quality parameter in aquaculture. The ideal DO range for most fish species is between 5 and 7 mg/L. Low DO levels can cause stress, disease, and mortality in fish. For example, in Rainbow Trout, DO levels below 3 mg/L can cause respiratory distress and DO levels below 2 mg/L can be fatal. Therefore, maintaining optimal DO levels is crucial for the survival and growth of fish[5].

1.7.1.4. Nitrogenous Compounds: Toxicity in the Environment

Nitrogenous compounds, such as ammonia and nitrite, are major water quality problems in aquaculture. According to the World Aquaculture Society, ammonia toxicity is the most significant problem, with toxic levels causing mortality and reduced growth rates in fish. To manage fluctuating nitrogenous compounds, it is essential to use efficient filtration systems, maintain proper feeding practices, and conduct regular water exchanges.High levels of ammonia, nitrite, and nitrate can be toxic to fish and other aquatic organisms. For example, ammonia is toxic at concentrations above 0.1 mg/L, nitrite at concentrations above 0.5 mg/L, and nitrate above 100 mg/L[5].

1.7.1.5. Total Suspended Solids and Turbidity: Affect Water Clarity and Growth

High levels of total suspended solids and turbidity in aquaculture can reduce light penetration, affecting the growth of aquatic plants and algae(essential food sources for some fish species). According to research by the University of Arkansas, high levels of total suspended solids can also lead to reduced growth rates and increased mortality in fish. Managing these levels using effective filtration systems and reducing sedimentation is necessary[5].

Chapter II:

Proposed solution design

2.1. Introduction

This chapter provides a brief overview of the most important technologies used in developing our project. We'll go through the hardware we used, including how they function, what they are used for and their features.

2.2 Choice of development platform

2.2.1 The ESP32-WROOM-32

ESP32-WROOM-32 is a powerful, generic Wi-Fi + Bluetooth® + Bluetooth LE MCU module that targets a wide variety of applications, ranging from low-power sensor networks to the most demanding tasks, such as voice encoding, music streaming and MP3 decoding.

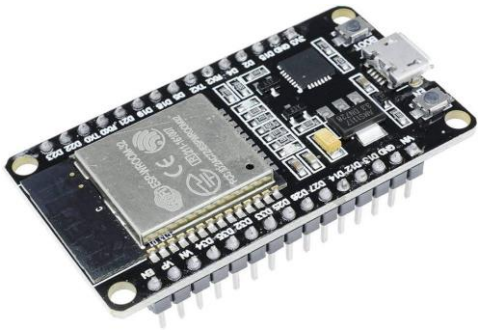


Figure II 1- ESP32 WROOM

At the core of this module is the ESP32-D0WDQ6 chip*. The chip embedded is designed to be scalable and adaptive. There are two CPU cores that can be individually controlled, and the CPU clock frequency is adjustable from 80 MHz to 240 MHz the chip also has a low-power coprocessor that can be used instead of the CPU to save power while performing tasks that do not require much computing power, such as monitoring of peripherals. ESP32 integrates a rich set of peripherals, ranging from capacitive touch sensors, SD card interface, Ethernet, high-speed SPI, UART, I2S, and I2C.

The integration of Bluetooth, Bluetooth LE and Wi-Fi ensures that a wide range of applications can be targeted, and that the module is all-around: using Wi-Fi allows a large physical range and direct connection to the Internet through a Wi-Fi router, while using Bluetooth allows the user to conveniently connect to the phone or broadcast low energy beacons for its detection. The sleep current of the ESP32 chip is less than 5 μA, making it suitable for battery powered and wearable electronics applications. The module supports a data rate of up to 150 Mbps, and 20 dBm output power at the antenna to ensure the widest physical range. As such, the module does offer industry-leading specifications and the best performance for electronic integration, range, power consumption, and connectivity.

The operating system chosen for ESP32 is freeRTOS with LwIP; TLS 1.2 with hardware acceleration is built in as well. Secure (encrypted) over the air (OTA) upgrade is also supported, so that users can upgrade their products even after their release, at minimum cost and effort.

2.2.1.1 Advantages of Using ESP32-WROOM in The System

Choosing the ESP32-WROOM for a tilapia water monitoring system offers several advantages. The ESP32-WROOM features a dual-core processor, allowing for efficient handling of multiple tasks, such as sensor data processing, communication, and running complex algorithms. It includes both Wi-Fi and Bluetooth capabilities, enabling easy and reliable wireless data transmission to a cloud server or a local device for real-time monitoring and control. Despite its high performance, the ESP32-WROOM is designed for low power consumption, making it suitable for continuous monitoring applications, especially in remote or battery-powered setups. With numerous GPIO pins, ADC channels, and DAC outputs, the ESP32-WROOM can interface with various sensors (pH, turbidity, temperature, ammonia) and actuators required for water quality monitoring. The 12-bit ADC in the ESP32-WROOM ensures precise readings from analog sensors, which is crucial for accurate water quality measurements. Additionally, the ESP32-WROOM benefits from a robust ecosystem, including extensive libraries, development tools, and community support, simplifying development and troubleshooting. Finally, the ESP32-WROOM offers a powerful feature set at a competitive price point, making it an economical choice for comprehensive water monitoring systems. Overall, the ESP32-WROOM's performance,

connectivity, and versatility make it an excellent choice for a reliable and efficient tilapia water monitoring system.

2.2.1.2 Comparison of ESP32-WROOM to Other Microcontrollers

Table II 1- Comparison between Arduino Uno, NodeMCU, ESP32 S2 & ESP WROOM 32

Feature	Arduino Uno	Node MCU	ESP32-S2	ESP32-WROOM
Processor	ATmega328P	ESP8266	Single-core Xtensa LX7 32 Bits	Dual-core Xtensa LX6 32 bits
Clock Speed	16 MHz	80/160 MHz	240 MHz	160/240 MHz
Flash Memory	32 KB	4 MB	128 KB	448 KB
SRAM	2 KB	128 KB	320 KB	520 KB
GPIO Pins	14 (6 PWM)	17	43	34
ADC Channels	6(10 Bits)	1(10 Bits)	20(12 Bits)	18(12 Bits)
DAC Channels	None	None	2	2
I2C	1	2	2	2
SPI	1	2	4	3
UART	1	1	2	3
Wi-Fi	NO	YES	YES	YES
Bluetooth	NO	NO	YES	NO
Power Consumption	Moderate	Low	Low to Moderate	Low to Moderate

2.3. Electronic components used

2.3.1. The serial real-time clock

The DS1307 serial real-time clock (RTC) is a low power, full binary-coded decimal (BCD) clock/calendar plus 56 bytes of NV SRAM. Address and data are transferred serially through an I2C, bidirectional bus. The clock/calendar provides seconds, minutes, hours, day, date, month, and year information. The end of the month date is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24- hour or 12-hour format with AM/PM indicator. The DS1307 has a built-in power-sense circuit that detects power failures and automatically switches to the backup supply. Timekeeping operation continues while the part operates from the backup supply [32].

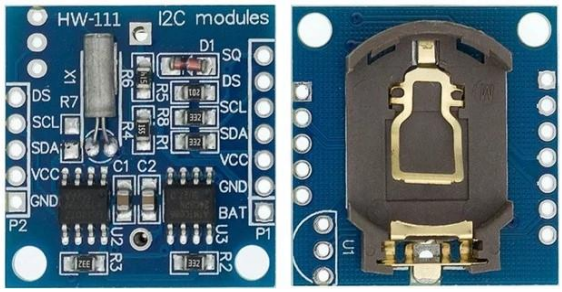


Figure II 2- DS1307 Real-Time Clock

2.3.1.1 FEATURES OF THE RTC

- Real-Time Clock (RTC) Counts Seconds, Minutes, Hours, Date of the Month, Month, Day of the week, and Year with Leap-Year Compensation Valid Up to 2100.
- 56-Byte, Battery-Backed, Non-volatile (NV) RAM for Data Storage.
- I2C Serial Interface.
- Programmable Square-Wave Output Signal.
- Automatic Power-Fail Detect and Switch Circuitry.
- Consumes Less than 500nA in Battery- Backup Mode with Oscillator Running.

- Optional Industrial Temperature Range: -40°C to +85°C.
- Available in 8-Pin Plastic DIP or SO.
- Underwriters Laboratory (UL) Recognized.

2.3.2 The SD Card Module

SD Card Module is a compact and versatile module designed for interfacing SD (Secure Digital) and micro SD cards with microcontrollers and single-board computers such as Arduino and Raspberry Pi. It provides an accessible solution for storing and retrieving data in various electronics projects, from data logging to multimedia applications.



Figure II 3- SD Card Module

2.3.2.1 System Functionality

SD Card Module operates using the Serial Peripheral Interface (SPI) protocol, enabling seamless communication with host devices like Arduino or an esp32. Here is how it functions:

- **SD Card Compatibility**: The module supports both standard SD cards and micro SD cards (via an adapter), offering flexibility in storage options based on project requirements.
- **SPI Communication**: It utilizes SPI for data exchange between the module and the host microcontroller. This communication method is efficient and widely supported in the embedded systems community.
- **Voltage Regulation**: The module typically operates at 3.3V logic levels, making it compatible with most modern microcontrollers. It often includes voltage regulators onboard to ensure stable operation across different power supply scenarios.

- **File System Support**: It is compatible with FAT16 and FAT32 file systems commonly used with SD cards, simplifying data management and access.
- **Hardware Interface**: The module includes standard pins for SPI communication (e.g., MOSI, MISO, SCK) and additional pins for power supply (VCC, GND) and chip select (CS), facilitating straightforward integration into projects.
- **Utility Libraries**: Often, DFRobot provides Arduino libraries and example codes to facilitate easy setup and usage, reducing development time for incorporating SD card functionalities into projects.

2.3.3 The Wi-Fi module esp8266

The ESP8266 is a highly versatile microcontroller renowned for its integrated Wi-Fi capabilities, developed by Espressif Systems. It boasts a robust Ten-silica L106 32-bit microcontroller core that operates at frequencies up to 80 MHz, ensuring reliable performance across various applications.



Figure II 4- ESP8266 WiFi Module

2.3.3.1 System Functionality

Functionally, the ESP8266 integrates seamlessly into Wi-Fi networks using 802.11 b/g/n standards, making it versatile for a wide range of IoT and connected device applications. Its built-in TCP/IP stack supports multiple TCP and UDP connections, allowing devices to communicate concurrently over Wi-Fi. This capability enables real-time data streaming, remote monitoring, and control applications with minimal latency [35]. The microcontroller's ability to operate as a standalone device or connect to existing networks via AP (Access Point), STA (Station), or AP+STA modes further enhances its adaptability [35]. Security features such as WPA/WPA2 PSK and WEP ensure secure data transmission, meeting stringent IoT security requirements.

2.3.3.2 The key feature of ESP8266

Key features of the ESP8266 include its 32-bit Tensilica microcontroller core running at speeds up to 80 MHz (overclock able up to 160 MHz), supported by 32 KB of instruction RAM and up to 80 KB of user data RAM [35]. Its integrated 32-bit SPI flash memory provides ample storage for firmware and data. The microcontroller also features a generous number of GPIO pins (usually around 17), which can be configured for digital input/output, PWM output, I2C communication, SPI communication, and more[35]. This flexibility makes it suitable for interfacing with sensors, actuators, displays, and other peripherals commonly used in IoT and embedded systems. Additionally, the ESP8266's low power consumption and cost-effective design make it a popular choice for battery-powered and cost-sensitive applications [35]. Its compatibility with popular development environments like Arduino IDE and support for Lau scripting via NodeMCU firmware simplify development, while its extensive community support ensures access to libraries, forums, and tutorials for rapid prototyping and deployment.

2.4. Choice of Sensors

2.4.1 The Temperature sensor

The DS18B20 is a digital temperature sensor manufactured by Maxim Integrated, designed for precise temperature measurement in various applications. Utilizing the 1-Wire communication protocol, it simplifies connectivity by allowing multiple sensors to operate on a single data line. This sensor boasts a measurement range from -55°C to +125°C with an accuracy of ±0.5°C within the critical range of -10°C to +85°C. It operates efficiently across a voltage range of 3.0V to 5.5V, making it compatible with a wide array of microcontrollers and systems.



Figure II 5- Temperature sensor the DS18B20

2.4.1.1 System Function of The DS18B20

The DS18B20 operates using a 1-Wire communication protocol, which allows for easy integration with microcontrollers and the ability to daisy chain multiple sensors on a single data line [23]. Each DS18B20 has a unique 64-bit serial code, enabling precise addressing in multi-sensor setups. Upon receiving a command from the microcontroller, the DS18B20 converts the temperature sensed by its internal element into a 12-bit digital word within a conversion time of

up to 750 ms [23]. This conversion process involves an analog-to-digital converter (ADC) that translates the analog signal into a precise digital temperature reading [23].

The sensor's digital temperature data is stored in a 2-byte register, which can be read by the microcontroller. To ensure accurate readings, the DS18B20 uses a calibration process during its manufacturing, embedding calibration data within its memory [23]. This allows it to provide accurate temperature measurements over a wide range of conditions without requiring recalibration in the field. Additionally, the DS18B20 supports programmable resolution from 9 to 12 bits, allowing users to tradeoff between measurement precision and conversion time.

In "parasite power" mode, the DS18B20 can operate without a dedicated power supply by drawing power from the data line. This is particularly useful in applications where minimizing wiring complexity is crucial [23]. To handle power efficiently, the sensor includes an internal capacitor that stores charge during idle periods, ensuring sufficient power during data transmission and temperature conversion.

2.4.1.2 Benefits of Using the DS18B20 in Tilapia Water Monitoring Systems

The DS18B20 sensor is highly advantageous for tilapia water monitoring systems due to its high accuracy (±0.5°C) ensures precise temperature measurements, which are crucial for maintaining optimal water conditions for tilapia health and growth. Unlike other sensors that require multiple pins, the DS18B20 uses the 1-Wire communication protocol, allowing multiple sensors to be connected on a single data line. This significantly reduces the number of GPIO pins needed on the ESP32, freeing up resources for other functionalities. Furthermore, the DS18B20 outperforms many analog sensors by providing stable digital readings that are less susceptible to electrical noise and interference [24] , enhancing the reliability of the monitoring system.

Overall, the DS18B20 is a superior choice for accurate, efficient, and reliable temperature monitoring in tilapia aquaculture.

2.4.2 The PH Sensor

The PH-201H is a high-precision pH sensor designed for accurate measurement of the acidity or alkalinity in various solutions. Widely used in aquaculture, hydroponics, and laboratory settings [20], the PH-201H ensures reliable pH monitoring crucial for maintaining optimal conditions in sensitive environments. Its robust construction and high sensitivity make it suitable for continuous, real-time monitoring applications [20].



Figure II 6- The Ph sensor PH-201H

2.4.2.1 System Functionality of PH Electrode

The PH-201H electrode operates based on the principles of electrochemistry to measure the hydrogen ion concentration in a solution, which directly correlates to the solution's pH level. Here is a detailed explanation of how it works:

a. Construction of the pH Electrode

A typical pH electrode, including the PH-201H, consists of two main components:

- **Glass Electrode (Sensing Electrode):** Made of a special pH-sensitive glass that allows hydrogen ions to pass through, creating a measurable potential difference [21].
- **Reference Electrode:** Contains a stable reference solution (usually potassium chloride) that provides a constant reference potential [21].

The combination of these two electrodes forms an electrochemical cell that measures the potential difference caused by hydrogen ion concentration.

b. Measurement Principle

- **Ion Exchange Process:** When the pH electrode is immersed in a solution, hydrogen ions from the solution interact with the outer surface of the glass electrode, exchanging with other cations (positively charged ions) in the glass [21]. This exchange creates a potential difference across the glass membrane.
- **Potential Difference:** The potential difference between the sensing electrode and the reference electrode is influenced by the hydrogen ion concentration in the solution [21]. This difference is what the pH meter detects and measures.
- **Nernst Equation:** The potential difference (E) measured by the electrode is related to the pH of the solution through the Nernst equation [22]:

$$\boldsymbol{E = E_0 + \left(\frac{2.303 \times R\,T \times PH}{F}\right)} \qquad \textbf{(01)}$$

Where E0 is the standard electrode potential, R is the gas constant, T is the temperature in Kelvin, and F is the Faraday constant.

c. Analog Signal Generation

- **Voltage Output:** The pH electrode generates an analog voltage signal proportional to the pH level. Typically, this voltage ranges from about -0.7 volts to +0.4 volts as the pH varies from 0 to 14 [21].
- **Temperature Dependence:** The potential difference is temperature-dependent. Hence, many pH meters include automatic temperature compensation to adjust the pH value based on the solution's temperature [21].

d. Data Processing

- **Analog-to-Digital Conversion:** The analog voltage signal from the pH electrode is sent to a pH meter or a microcontroller (such as the ESP32). This device contains an analog-to-digital converter (ADC) that converts the analog signal into a digital signal [21].
- **Calibration:** Before accurate measurements can be taken, the pH sensor system must be calibrated using standard buffer solutions of known pH values (typically pH 4, 7, and 10). Calibration adjusts the meter to account for any deviations in the electrode's response [21].
- **Calculation of pH Value:** The digital signal is processed using the calibration data and the Nernst equation to compute the pH value. This value is then displayed on a digital readout or transmitted to a data logging system [21].

2.4.2.2 The Ph Sensor Module PH-4502C

The pH sensor module PH-4502C is a versatile and reliable tool designed for measuring the pH level of aqueous solutions [37]. It is widely used in various applications such as environmental monitoring, aquaculture, hydroponics, and water quality analysis [37]. The module is known for its ease of use, robustness, and accuracy in delivering consistent pH readings.

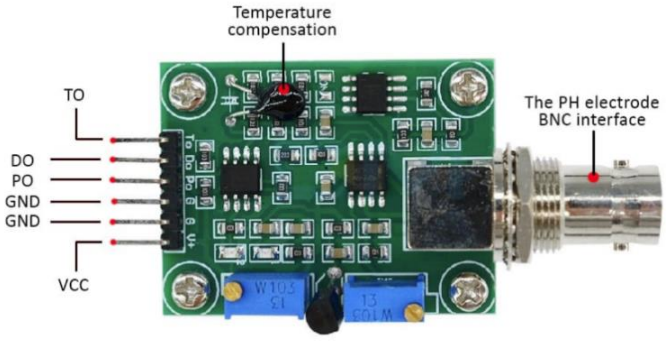


Figure II 7- Ph Sensor Module PH-4502C

a. Specifications

- Heating Voltage: 5±0.2V (AC - DC)
- Working Current: 5-10mA
- Detection Concentration Range: pH0-14
- Detection Temperature Range: 0-80°C
- Response Time: ≤ 5S
- Stability Time: ≤ 60S
- Power Consumption: ≤ 0.5W
- Working Temperature: -10-50°C (nominal temperature 20°C)
- Working Humidity: 95%RH (nominal humidity 65%RH)
- Service Life: 3 years
- Size: 42mm x 32mm x 20mm
- Output: Analog voltage signal output

b. Key Features

- **High Precision:** The PH-4502C module provides accurate pH measurements, crucial for applications requiring precise monitoring of water quality [36].
- **Easy Integration:** This module can be easily interfaced with microcontrollers, such as the ESP32, via its analog output [36]. It is particularly compatible with Arduino boards, making it a popular choice for DIY and educational projects.
- **Signal Conditioning:** The module includes built-in signal conditioning, which stabilizes the output signal, reduces noise, and ensures that the voltage signal is within the operational range of the connected microcontroller's ADC [36].
- **Temperature Compensation:** The PH-4502C is designed to account for temperature variations, providing more accurate pH readings even in fluctuating environmental conditions [36].
- **Durable pH Probe:** The module typically comes with the PH-201H pH probe, which is designed for durability and stability, offering consistent performance over time [36]. The probe can be easily replaced when necessary, extending the module’s lifespan.

Wide Application Range: Its versatility makes it suitable for various applications, including laboratory experiments, water treatment facilities, agricultural practices, and hobbyist projects [36].

2.4.2.3 Benefits of Using the PH Sensor in Tilapia Water Monitoring Systems

Using a pH sensor in the tilapia water monitoring system provides significant benefits by ensuring optimal water quality, which is crucial for the health and growth of the fish. The pH sensor offers real-time, accurate measurements of the water's acidity or alkalinity, enabling immediate detection and correction of pH imbalances. This continuous monitoring helps maintain a stable environment, preventing harmful conditions that could lead to disease or poor growth rates. Additionally, automated pH management reduces manual labor and enhances the efficiency of the aquaculture operation, leading to improved productivity and sustainability.

2.5. THE TDS SENSOR

The TDS Meter V1.0 Sensor is a precision instrument designed for measuring Total Dissolved Solids (TDS) in water. It is commonly used in various industries including aquaculture, hydroponics, drinking water quality assessment, and environmental monitoring. The sensor provides a quantitative measurement of the concentration of dissolved solids in parts per million (ppm) within a water sample [29]. This measurement is essential for assessing water purity, identifying contamination levels, and ensuring the suitability of water for specific applications.



Figure II 8- TDS sensor v1.0

2.5.1 Functionality System of TDS V1.0 Sensor

The TDS Meter V1.0 Sensor functions through conductivity measurement to assess the Total Dissolved Solids (TDS) content in water. It features two main electrodes submerged in the water sample, designed as conductivity electrodes [29]. These electrodes facilitate the generation of an electrical current proportional to the concentration of ions present, including salts, minerals, and other dissolved solids. The sensor operates by measuring electrical conductivity when immersed in water, a parameter directly correlated with ion concentration [30]. Periodic calibration using standard TDS solutions is essential to uphold accuracy and reliability. Upon measurement, the sensor produces an analog voltage signal proportional to the water's conductivity or TDS level, which is subsequently converted into a digital format via an Analog-to-Digital Converter (ADC) [30]. This digital signal undergoes processing by a microcontroller or dedicated processing unit, utilizing calibration data and algorithms to compute the TDS concentration in parts per million (ppm) or milligrams per liter (mg/L) [30].

2.5.2 Benefits of Using the TDS Sensor in Tilapia Water Monitoring Systems

Using the TDS Meter V1.0 Sensor in a tilapia water monitoring system provides several benefits crucial for aquaculture management. By accurately measuring Total Dissolved Solids (TDS) in water, the sensor enables continuous monitoring of water quality parameters essential for tilapia health and growth. It helps in maintaining optimal environmental conditions by detecting changes in TDS levels, which can indicate variations in nutrient concentrations, salinity, or pollution levels. This real-time monitoring capability allows for timely intervention, ensuring prompt adjustments to water quality parameters to prevent stress and diseases in tilapia. Additionally, the sensor's ability to provide precise TDS measurements aids in optimizing feeding regimes and water treatment strategies, thereby enhancing overall productivity and sustainability of tilapia farming operations. Moreover, by correlating TDS levels with ammonia concentrations, the sensor assists in assessing and managing ammonia levels in the water, crucial for maintaining a healthy aquatic environment and maximizing tilapia growth rates.

2.5.3 Turbidity sensor

The TS-300B turbidity sensor is an advanced instrument used extensively in water quality monitoring systems. It operates on the principle of light scattering and absorption to measure the turbidity or cloudiness of water. Turbidity is a crucial indicator of water quality as it reflects the presence of suspended particles, sediment, or organic matter that can affect aquatic ecosystems and human health [25]. The TS-300B sensor provides precise measurements by emitting light into the water sample and detecting the amount of scattered light [25].

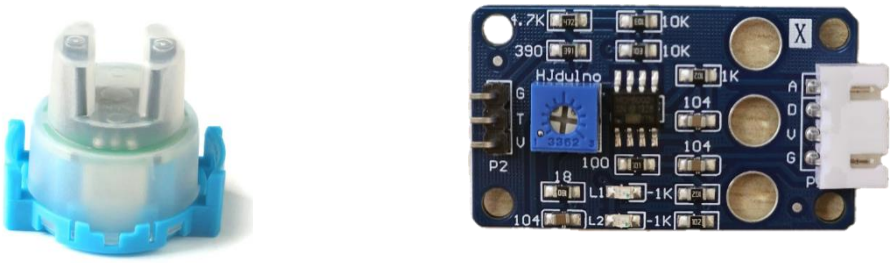


Figure II 9- TS-300B Turbidity sensor

2.5.3.1 Functionality System of TS-300B Sensor

The TS-300B turbidity sensor functions by utilizing a light scattering method to measure the turbidity, or cloudiness, of liquids based on the concentration of suspended particles within them. This sensor emits light into the liquid sample and detects the scattered light that results from interactions with particles present in the liquid. The intensity of the scattered light is directly proportional to the turbidity of the liquid, allowing the sensor to quantify turbidity levels accurately [25]. Typically calibrated to measure within specific ranges, the TS-300B is adaptable for various applications where monitoring and controlling turbidity are critical, such as in environmental monitoring for water quality assessment, industrial processes like wastewater treatment, and in research laboratories for scientific experiments [27]. Output from the sensor is often provided in units such as NTU (Nephelometric Turbidity Units) or FNU (Formazin Nephelometric Units), ensuring compatibility with standard turbidity measurement protocols [27]. Installation involves immersing the sensor in the liquid being measured, either directly or via a probe, and connecting

it to a measurement device or system that interprets and displays the turbidity readings. Regular maintenance, including cleaning to prevent contamination that could affect accuracy [27], is essential to maintain reliable performance over time.

2.5.3.2 Benefits of using the turbidity Sensor in Tilapia Water Monitoring Systems

Integrating the TS-300B turbidity sensor into a tilapia aquaculture system provides essential benefits for water quality management. By accurately measuring turbidity levels, the sensor helps maintain optimal conditions crucial for tilapia health and growth. This capability enables aqua culturists to monitor and adjust filtration and water treatment processes in real-time, ensuring stable and conducive environments for the fish. The sensor's role in automating data collection also enhances operational efficiency, allowing timely interventions to mitigate potential risks and optimize production outcomes in tilapia far

Chapter 03:

Implementation, Calibration, Tests and Results.

3.1. Introduction

In our project, we focus on ensuring a healthy and secure environment for tilapia by leveraging modern technology. Using the ESP32 microcontroller programmed using the Arduino IDE software with C /C++ language, and a suite of sensors including pH, temperature, turbidity, and conductivity.

In this chapter, we will detail the overall design of the project, explaining the steps and methodologies employed to achieve the main task of continuous water quality monitoring for tilapia. This includes the integration of sensors, data acquisition, and real-time data visualization on a web platform, ensuring a comprehensive and practical approach to aquaculture management.

3.1 Synoptic Diagram

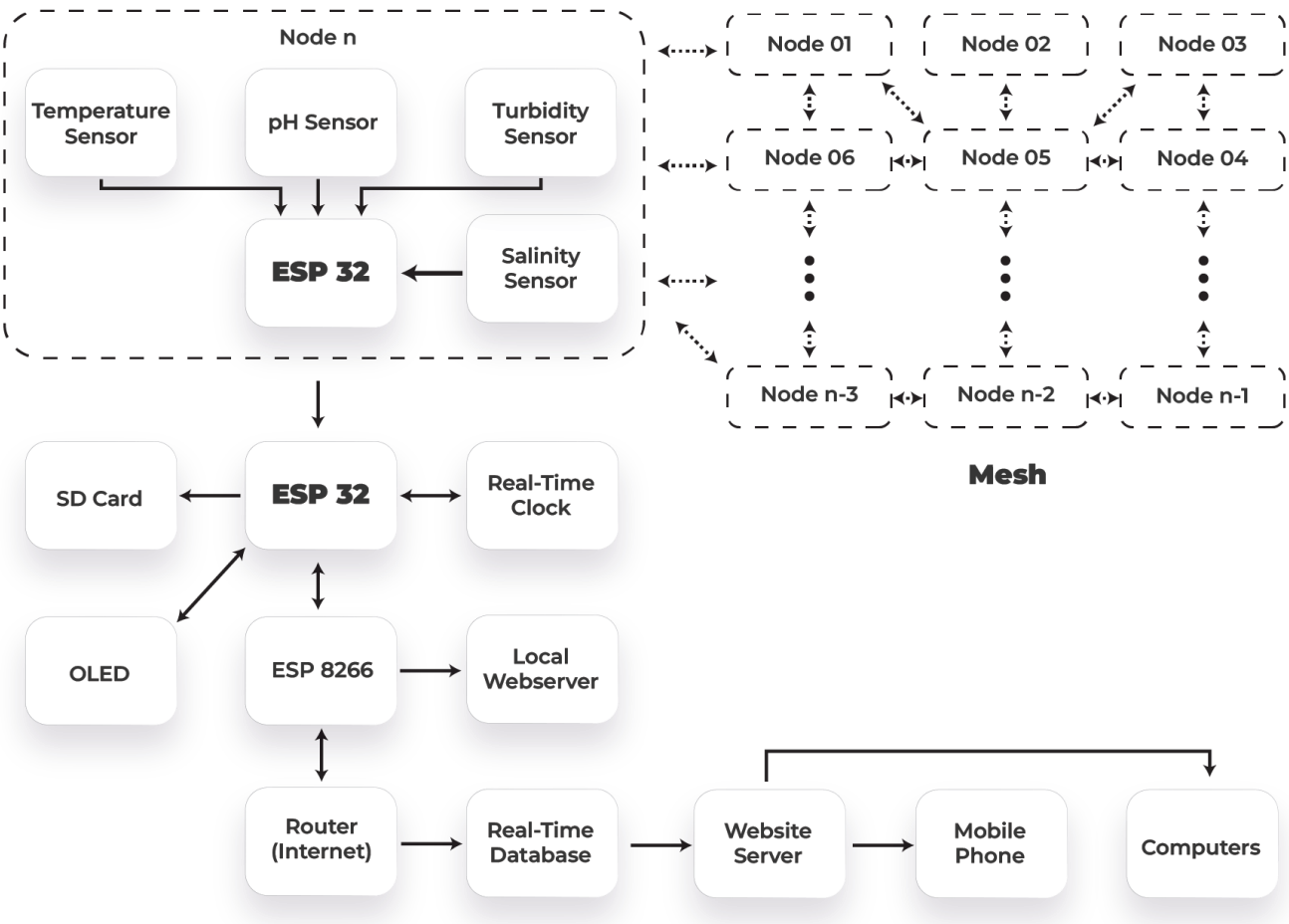


Figure III 1- Synoptic Scheme of the system

This Figure represents the synoptics of our systems, we have multiple nodes with an undefined number of nodes with multiple possibilities that are connected to a mesh that transfer all the data of Sensor readings from each node to the sink node which transfers all the recieved data to the wifi module that connects to internet, Sends data to an RTD and then broadcasts it to an online Website server.

3.2 Electrical Diagram of The System

3.2.1 End node Electrical Scheme:

This figure represents the electric Schema for the end node, this schema has a power supply which consists of two batteries of 3.7 volts which give the equivalent of 7.4V that passes into a voltage regulator which regulates the voltage into 5V, the diode protects the Microcontroller in case the batteries were placed the opposite way, and the LED is an indicator that verifies the functionality of the batteries.

The microcontroller is an ESP32 that has our sensor attached to, we have our turbidity, TDS and pH sensors linked with ADC input pins and the Temperature sensor is linked with a Digital input pin which serve the role of measuring water parameters.

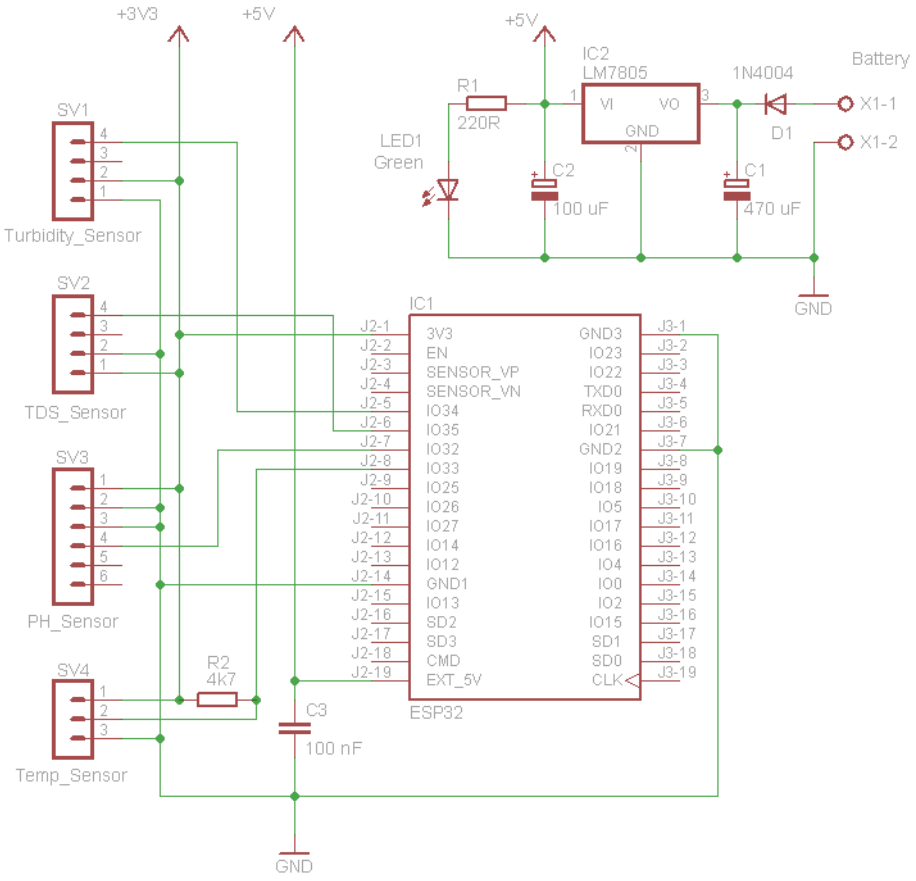


Figure III 2- Electrical Scheme of the End node

3.2.2 Sink node Electrical Scheme:

Sink Node This Figure represents the Electric schema of the Sink node, this node is directly supplied using a 5V power, this node has an OLED Display and an RTC Module that is linked with the ESP32 using I2C Communication Protocol with each one of them having their own individual address, the SD card reader is linked to the ESP32 using SPI protocol that has Master and Slave, have the reader to act as slave and the ESP32 as master, the capacitors were added to maintain a stable power supply.

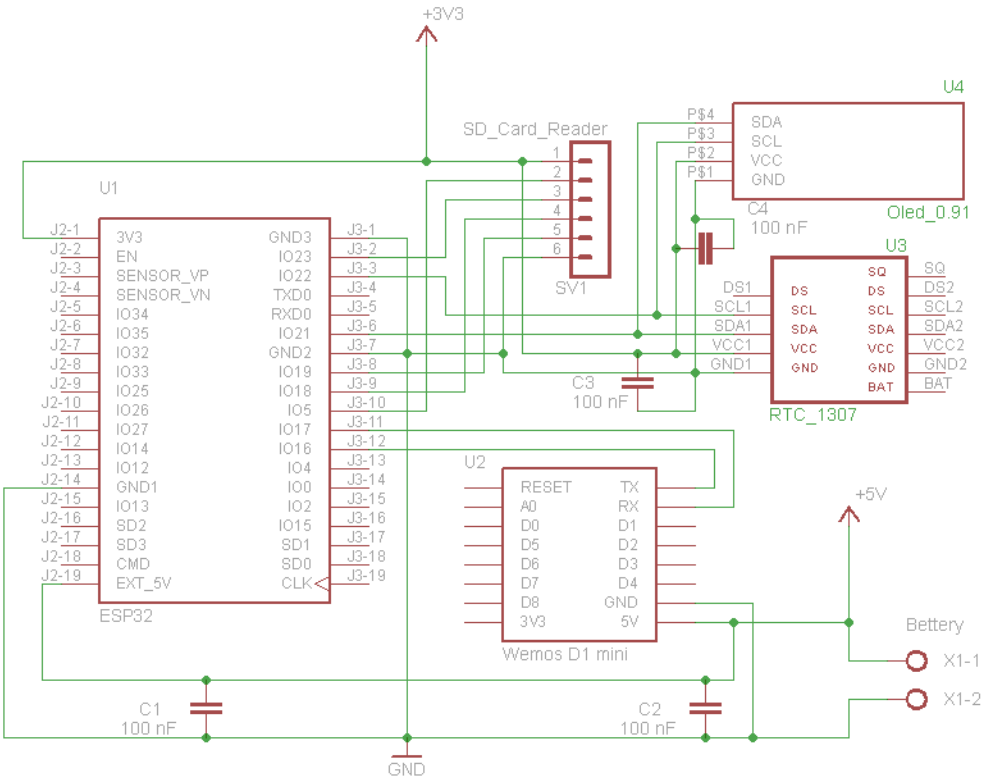


Figure III 3- Electrical Scheme of the Sink Node

3.3 The System Program diagrams

3.3.1 Collector node Program diagram:

This diagram represents the program functionality of the collector node code, it includes initializing the WiFi Mesh, SD Card, UART Interface and the RTC module, it is responsible of delivering the information gained to WiFi Module and save logs to the SD Card.

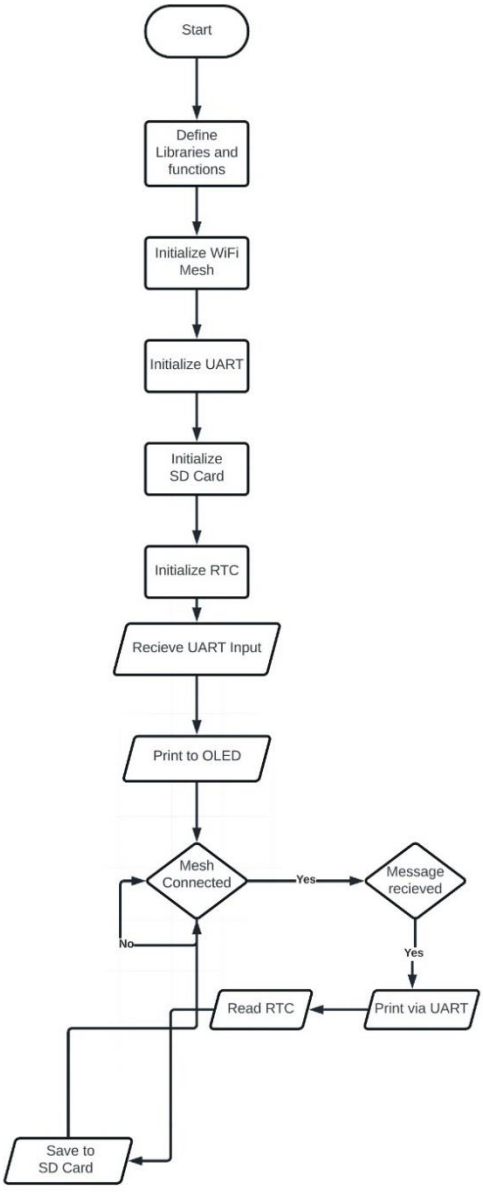


Figure III 4- Collector node program diagram

3.3.2 Wi-Fi mesh End node program diagram:

This Diagram represents the functionality of End node code, it initializes the WiFi Mesh and Sensors and acts as a measurement and communication device, which trades information with other nodes having all of the nodes measures received and sent.

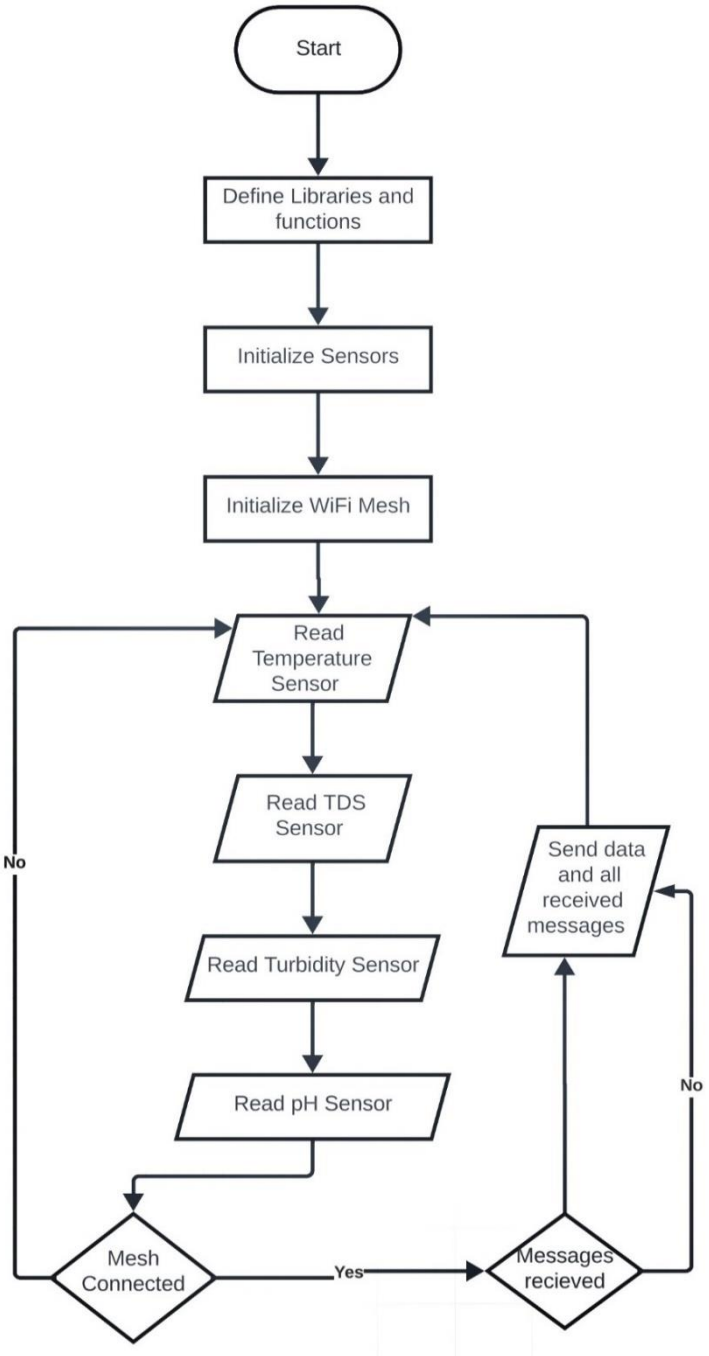


Figure III 5- End Node program diagram

3.3.3 WiFi Module program diagram:

This Diagram represents the WiFi Module functionality code, it initializes a wifi communication with a router that has internet access, reads UART signal from the collector and sends it over to a Real-Time Database.

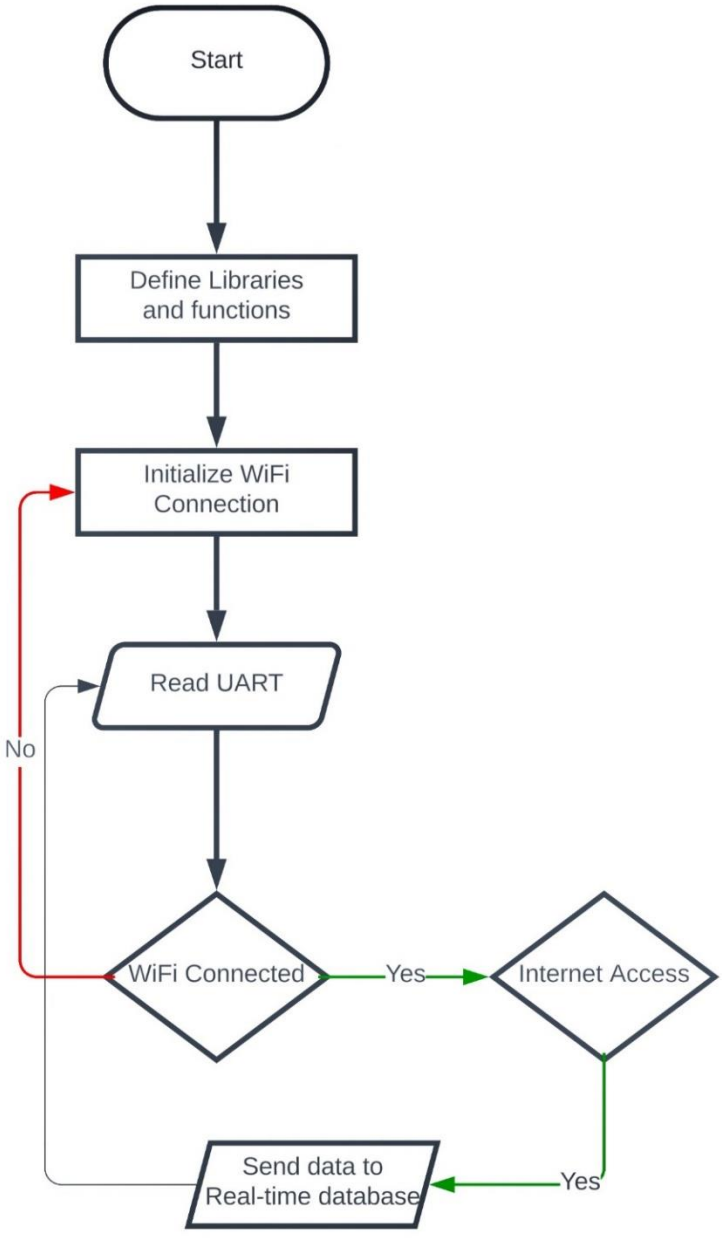


Figure III 6- WiFi Module Program diagram

3.4 System Working Principle

The water monitoring system for a tilapia farm consists of two main nodes: the end node and the sink node. This system is designed to ensure robust data collection and transmission for real-time monitoring and analysis of water quality, facilitating optimal conditions for tilapia growth.

3.4.1End Node Data Collection

The end node is based on an ESP32 microcontroller and is equipped with four primary sensors: turbidity, conductivity, temperature, and PH. These sensors collect essential data from the tilapia pool. The system is designed with scalability in mind, allowing additional sensors to be integrated as needed. The ESP32 communicates with other nodes via a Wi-Fi mesh network, ensuring reliable data transmission across the system.

3.4.2 Sink Node Data Storage and Transmission

The sink node also utilizes an ESP32 microcontroller and is equipped with a Real-Time Clock (RTC) and an SD card module for offline data storage. Additionally, it uses an ESP8266 Wi-Fi module for network communication, connected via UART. The sink node retrieves data from the SD card and uploads it to a Firebase dataset using the Wi-Fi module. This data is then updated on a hosted website every 10 minutes, ensuring timely and accurate data availability.

3.4.3 Communication and System Robustness

Both the sink node and the end node communicate using the Wi-Fi mesh network, creating a robust dual communication setup. This configuration ensures continuous data collection and transmission, even if individual nodes experience connectivity issues. The system is flexible and scalable, allowing for the addition of more sensors and nodes as required, ensuring the farm can maintain optimal water conditions for tilapia growth.

3.5 System Hardware Communication and Operation Sequence

3.5.1 Operational Sequence of end node ESP32 and pH Sensor Communication

The ESP32 microcontroller communicates with the pH-4502C module through its analog-to-digital converter (ADC) pin 32 [36]. The communication protocol employed in this setup is based on analog signal processing, where the pH-4502C module outputs a voltage corresponding to the pH level of the solution. This voltage signal, ranging from 0 to 5 volts [36], is read by the ESP32's ADC pin. The ESP32 then converts this analog signal into a digital value, which can be processed to determine the pH level. The ADC of the ESP32 is capable of providing high-resolution readings, ensuring accurate and reliable pH measurements.

The pH probe used in this setup is the PH-201H, which measures the hydrogen ion concentration in water [21], translating it into an electrical potential. When the probe is immersed in the water, it generates a voltage signal proportional to the pH level of the solution [21]. The pH-4502C module conditions this voltage signal, ensuring it is within the operational range of the ESP32's ADC. The module stabilizes the signal, removes noise, and adjusts the output to match the expected input range of the microcontroller, facilitating precise and consistent readings.

3.5.1.1 Data Collection, Sorting, and Averaging

The method used for data collection, sorting, and averaging in the code is designed to enhance the accuracy and stability of the pH readings from the sensor. By taking multiple readings (10 in our case) and storing them in an array, the code can mitigate the impact of transient noise or fluctuations in the sensor output. Sorting the array and then averaging the middle six values (excluding the lowest two and highest two) helps to eliminate outliers and obtain a more reliable representation of the sensor's actual output. This approach improves the precision of the pH measurement by focusing on the most consistent data points.

The pH voltage calculation involves converting the averaged digital readings from the ADC into a corresponding voltage. The ADC on the ESP32 converts the analog voltage signal from the pH sensor into a digital value between 0 and 4095.The formula used is:

$$\boldsymbol{PHVOL = \{(float) \times avgValue \times 3.3)/4095/6\}} \quad \textbf{(2)}$$

AvgValue is the sum of the middle six sorted readings,

3.3 represents the reference voltage

4096 is the ADC resolution (12-bit).

6 is the number of readings averaged.

This calculation translates the digital average back into the actual voltage level read from the sensor, providing a voltage that can then be used to determine the pH value. Finally, the pH value calculation converts the measured voltage into a pH reading using the formula:

$$\boldsymbol{phValue = -5.70 \times PHVol + calibration} \quad \textbf{(3)}$$

In this equation, **pHVol** is the previously calculated voltage, **-5.70** is a scaling factor that relates the voltage to the pH value. This factor is determined based on the characteristics of the pH sensor and may need adjustment through calibration. The **calibration** term is a constant added to fine-tune the pH reading, ensuring it matches known pH standards.

3.5.2 Operational Sequence off end node ESP32 and Temperature Sensor Communication

The ESP32 microcontroller communicates with the DS18B20 temperature sensor using a 1-Wire interface, connected through pin 33. The 1-Wire communication protocol is a low-speed, data transmission protocol that uses a single data line plus ground for communication. This protocol allows multiple 1-Wire devices to be connected on the same bus, making it efficient for temperature sensing applications with multiple sensors [23]. To stabilize the data line (DQ), this setup includes ensuring a 4.7kΩ pull-up resistor is connected between the GPIO pin and the 3.3V power supply [23]. The ESP32's GPIO pin 33 is configured to handle the 1-Wire communication, enabling it to send commands and receive temperature data from the DS18B20 sensor.

The DS18B20 temperature sensor operates by converting temperature readings into digital signals that can be read by a microcontroller. It has an internal temperature sensor and a digital-to-analog converter (DAC) that translates the sensor's analog signal into a digital value [23]. The sensor operates within a temperature range of -55°C to +125°C with an accuracy of ±0.5°C in the range of -10°C to +85°C. It has a unique 64-bit serial code, allowing multiple DS18B20 sensors to be connected to the same One Wire bus without address conflicts [23]. When the sensor receives a command from the master device, it performs a temperature conversion and stores the result in its scratchpad memory, from where it can be read by the master.

The ESP32 utilizes the One Wire and Dallas Temperature libraries to manage communication and data processing. Upon requesting temperature data, the ESP32 sends a command to the sensor to initiate a temperature conversion. The DS18B20 then performs the conversion and stores the digital temperature value in its memory. The ESP32 reads this digital value and converts it into a temperature reading in Celsius. This conversion is handled by the Dallas Temperature library, which interprets the sensor's raw data according to its resolution and converts it to a human-readable temperature value.

3.5.3 Operational Sequence of end node ESP32 and Conductivity Sensor Communication

For communication, The TDS sensor is connected to the ESP32 via the analog-to-digital converter (ADC) pin 34. The ADC on the ESP32 converts the analog voltage output from the sensor into a digital value. The ADC has a 12-bit resolution, meaning it can represent the analog input as a digital value ranging from 0 to 4095. This digital value corresponds to the voltage level read from the sensor.

The TDS sensor works by measuring the electrical conductivity of the water, which is directly related to the concentration of dissolved solids. When the sensor is submerged in water, it outputs an analog voltage that varies with the TDS concentration [30]. The sensor's analog output is read by the ESP32 at regular intervals. To ensure the readings are stable and accurate, a median filter is applied to the collected data [30]. The median filter sorts the readings and selects the middle

value, effectively reducing noise and eliminating outliers. This filtering process helps in obtaining a more accurate and stable average voltage, which is crucial for precise TDS measurement.

Once the filtered average voltage is obtained, the ESP32 transforms this voltage into a TDS value. The first step is to convert the raw ADC reading to a voltage value using the reference voltage (VREF) of the ESP32, which is 3.3V.

$$\boldsymbol{avreageVoltage = \frac{getMedianNum() \times VREF}{4096}} \quad \textbf{(4)}$$

- VREF is the reference voltage (3.3V),
- 4096 is the maximum value of the 12-bit ADC.
- AnalogBufferTemp array used for the median filtering algorithm.

To adjust the voltage reading based on current water temperature we apply it to a compensation formula this adjustment is necessary because the conductivity of water changes with temperature.

$$\boldsymbol{componsastioncoef = 1.0 + 0.02 \times (T - 25)} \quad \textbf{(5)}$$

The compensated voltage is then fed into a polynomial equation, which models the relationship between the voltage and the TDS value. The equation converts the compensated voltage into a TDS value in parts per million (ppm). This final TDS value.

$$\boldsymbol{TDS\ Value = (133.42\ componV^3 - 225.86 \times componV^2 + 857.39 \times componV^1) \times 0.5} \quad \textbf{(6)}$$

3.5.4 Operational Sequence of end node ESP32 and Turbidity Sensor Communication

And for the connection between the ESP32 and the TS-300B turbidity sensor initially, the ESP32 configures a dedicated ADC pin, GPIO35, to receive analog signals from the TS-300B turbidity sensor. This setup establishes a stable and reliable connection between the sensor's analog output (AOUT) and the ESP32, ensuring accurate signal acquisition and processing.

Upon initialization, the ESP32 powers the TS-300B turbidity sensor using its 3.3 V power supply, as specified for the sensor. The TS-300B turbidity sensor operates by measuring the amount of light that is scattered by particles suspended in water. The sensor has an LED that emits light into the water sample, and a photodetector that measures the intensity of light that is scattered back to the sensor. The more particles present in the water, the higher the turbidity and the greater the scattering of light. The sensor then outputs an analog voltage proportional to the turbidity level of the water. This voltage is higher when the water is clear (less turbid) and lower when the water is cloudy or dirty (more turbid).

The ESP32 reads the analog voltage output from the turbidity sensor via its ADC pin 35. The analog reading, which ranges from 0 to 4095 due to the 12-bit resolution of the ESP32's ADC, is converted by applying the linear calibration equation, the ESP32 maps the analog sensor voltage directly to turbidity values in NTU

$$\boldsymbol{sensor\ voltage} = \frac{\boldsymbol{analogread(turbidity)} \times \mathbf{3.3}}{\mathbf{4095}} \quad \textbf{(7)}$$

Based on the turbidity value, the esp32 also provides a qualitative assessment of water quality, categorizing it as CLEAR, CLOUDY, or DIRTY

3.5.5 Operational Sequence of ESP 8266 and Peripherals (RTC DS1307 and SD Card Module)

The operational sequence in the sink node involves coordinated interaction between the ESP32 microcontroller and its peripherals, namely the RTC DS1307 and the SD card module. The communication protocol between the ESP32 and the SD card module is SPI (Serial Peripheral Interface), which allows for high-speed data transfer. The ESP32 communicates with the RTC DS1307 using the I2C (Inter-Integrated Circuit) protocol, which enables efficient data exchange with minimal pin usage. Upon powering up, the ESP32 initializes its internal components and configures the Wi-Fi mesh network to establish communication with the end nodes. The ESP32 then synchronizes the system time with the RTC DS1307, either setting the current date and time or retrieving it if previously configured. The SD card module is also initialized by checking for the presence of the SD card and mounting the file system to prepare for data storage.

The ESP32 periodically receives sensor data from the end nodes via the Wi-Fi mesh network. This data includes readings from turbidity, conductivity, temperature, and pH sensors. Upon receiving the data, the ESP32 timestamps each entry using the current time from the RTC DS1307, ensuring precise logging. The ESP32 then writes the timestamped data to the SD card in a structured format such as text. Each end node has its own file on the SD card, ensuring that data from different nodes is stored separately and can be easily accessed.

3.6 Communication Protocols Used in the System

3.6.1 Wi-Fi Mesh:

A Wi-Fi mesh network is a network topology that uses multiple interconnected nodes to provide seamless, widespread, and robust wireless coverage. Unlike traditional Wi-Fi networks, which rely on a single access point (AP) and can experience signal degradation in distant areas, a mesh network consists of several nodes (or mesh points) that communicate with each other to extend coverage and improve reliability. Each node in a mesh network acts as both a transmitter and a receiver, allowing data to be routed dynamically through the network [33].

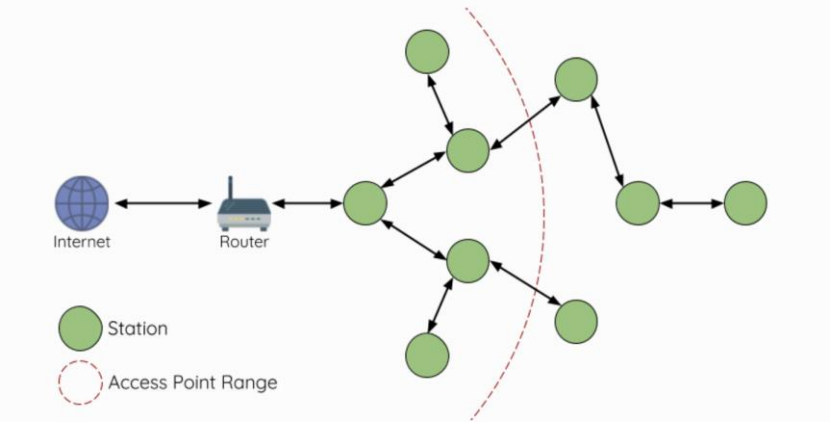


Figure III 7- WIFI-MESH Network Architecture

3.6.2 Comprehensive Overview of Wi-Fi Mesh Networks

Wi-Fi mesh networks operate on decentralized principles, where nodes autonomously form connections and adapt to network changes in real-time. This section explores the intricate mechanisms of mesh networks, including their formation, self-healing capabilities, data routing strategies, load balancing techniques, scalability benefits, and robust security measures. Understanding these aspects illuminates how mesh networks effectively support Continuous and reliable data transmission in diverse environments [34].

3.6.2.1 Network Formation and Self-Healing

Upon powering on, each node within the mesh network broadcasts its presence to neighbouring nodes, facilitating automatic discovery and connection establishment. This decentralized approach eliminates single points of failure by enabling nodes to communicate with multiple peers simultaneously. Central to the mesh topology is its self-healing functionality, where the network dynamically reroutes data through alternate nodes in response to node failures or lost connections. This built-in redundancy ensures uninterrupted network availability and reliability, ensuring seamless communication even during disruptions or failures [34].

3.6.2.2 Data Routing and Load Balancing

In a Wi-Fi mesh network, data packets are dynamically routed through multiple paths to their destination, leveraging each node's routing intelligence to determine the most efficient route based on current network conditions. This adaptive routing capability not only enhances reliability but also prevents congestion by distributing network traffic evenly across all nodes. This load balancing mechanism optimizes overall network performance, ensuring consistent data throughput and minimizing the risk of any single node becoming a bottleneck [34].

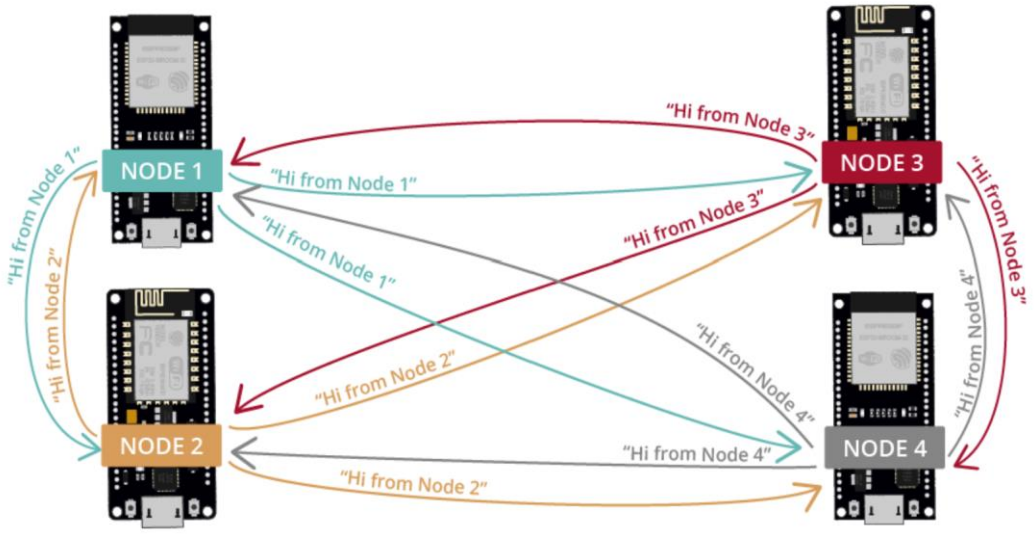


Figure III 8- Mesh Data Routing

3.6.2.3 Scalability

Mesh networks are highly scalable, meaning new nodes can be added to the network without significant reconfiguration. As new nodes join, they automatically integrate into the existing mesh, extending coverage and enhancing network capacity [34].

3.6.2.4 Security

Mesh networks often employ robust encryption methods to secure data transmissions between nodes. Each node can authenticate and encrypt data, ensuring that unauthorized access and data breaches are minimized [34].

3.6.3 Application of Wi-Fi Mesh Network in the System

3.6.3.1 Wi-Fi Mesh Network Architecture

In the water monitoring system for the tilapia farm, a Wi-Fi mesh network is employed to ensure robust and reliable communication between multiple sensor nodes (end nodes) and a central sink node. The Wi-Fi mesh network uses ESP32 microcontrollers at both ends, creating a flexible and scalable network topology.

3.6.3.2 Mesh Network Formation

The mesh network is formed using the `painlessMesh` library, which simplifies the creation and management of the mesh. The network does not rely on a single central router; instead, each node can communicate with its neighbouring nodes directly. This decentralization allows for dynamic routing and self-healing capabilities. If one node goes down or experiences connectivity issues, the data is automatically rerouted through other available nodes, ensuring continuous operation.

3.6.3.3 Node Initialization and Communication

Each node in the network, whether an end node or the sink node, initializes its Wi-Fi in mesh mode using the `mesh.init()` function. The nodes use a predefined mesh network name (`MESH_PREFIX`) and password (`MESH_PASSWORD`) to join the network.

3.6.3.4 Channel Scanning and Selection

To optimize connectivity, the nodes periodically scan available Wi-Fi channels using the `WiFi.scanNetworks()` function. This function provides a list of detected Wi-Fi networks and their signal strengths. The mesh network algorithm then selects the least congested channel to minimize

interference and maximize data transmission efficiency. This dynamic channel selection ensures the network remains robust even in environments with multiple Wi-Fi networks.

3.6.3.4 Data Transmission

The end nodes, equipped with various sensors (turbidity, conductivity, temperature, and pH sensors), collect data and transmit it to the sink node. The `painlessMesh` library handles the data transmission, allowing messages to be sent as broadcasts or directly to specific nodes.

- **Data Collection:** Each end node collects sensor data at regular intervals. This data is processed and formatted into a JSON string for easy parsing and transmission.
- **Broadcasting Data:** The formatted JSON data is broadcasted over the mesh network using the `mesh.sendBroadcast()` function. This function ensures that the data is transmitted to all nodes within the network, including the sink node.
- **Receiving Data:** The sink node receives the broadcasted data using the `mesh.onReceive()` callback function. This function is triggered whenever a message is received, allowing the sink node to parse and process the incoming data.

3.6.3.5 Self-Healing and Dynamic Routing

One of the key advantages of a mesh network is its self-healing capability. If a node fails or loses connectivity, the network automatically reroutes the data through other nodes. The `painlessMesh` library continuously monitors the network topology and updates the routing paths as needed, ensuring that data transmission remains uninterrupted.

3.6.3.6 Sink Node Operations

The sink node, also based on an ESP32, performs several critical functions:

- **Data Storage:** It stores the received data on an SD card for local logging. This ensures that there is a backup of all sensor data, which is crucial for historical analysis and troubleshooting.

- **Data Upload:** Using an ESP8266 Wi-Fi module, the sink node uploads the collected data to a remote server, such as Firebase or a hosted website. This allows for remote monitoring and analysis of the water quality in the tilapia farm.
- **.Real-Time Clock (RTC):** The sink node includes an RTC to timestamp the received data accurately. This is important for correlating the sensor data with specific time periods and identifying trends or anomalies.

3.6.3.7 Mesh Network Synchronization

The `painlessMesh` library also handles time synchronization across the network. The sink node can act as a time server, broadcasting the current time to all end nodes. This ensures that all nodes in the network have a synchronized time reference, which is crucial for accurate data logging and analysis.

3.6.3.8 Network Scalability

The mesh network is highly scalable. New end nodes can be added to the network without significant changes to the existing infrastructure. Each new node will automatically join the network, participate in data collection, and help in routing the data. This scalability makes the system adaptable to varying sizes of tilapia farms and different monitoring requirements.

3.6.3.9 Security

The mesh network uses a predefined password (`MESH_PASSWORD`) for authentication, ensuring that only authorized nodes can join the network. This prevents unauthorized access and ensures the integrity and confidentiality of the transmitted data.

3.6.4 Overview Explanation of UART Communication

UART stands for universal asynchronous receiver / transmitter and defines a protocol, or set of rules, for exchanging serial data between two devices. UART is very simple and only uses

two wires between transmitter and receiver to transmit and receive in both directions. Both ends also have a ground connection [38]. Communication in UART can be simplex (data is sent in one direction only), half-duplex (each side speaks but only one at a time), or full duplex (both sides can transmit simultaneously) [38]. Data in UART is transmitted in the form of frames.

3.6.4.1 Timing and synchronization of UART protocols

One of the big advantages of UART is that it is asynchronous – the transmitter and receiver do not share a common clock signal. Although this greatly simplifies the protocol, it does place certain requirements on the transmitter and receiver [39]. Since they do not share a clock, both ends must transmit at the same, pre-arranged speed in order to have the same bit timing. The most common UART baud rates in use today are 4800, 9600, 19.2K, 57.6K, and 115.2K. In addition to having the same baud rate, both sides of a UART connection also must use the same frame structure and parameters [39]. The best way to understand this is to look at a UART Frame.

3.6.4.2 UART Protocols Data Transmission

In UART, the mode of transmission is in the form of a packet. The piece that connects the transmitter and receiver includes the creation of serial packets and controls those physical hardware lines [39]. A packet consists of a start bit; data frame, a parity bit, and stop bits.



Figure III 9- UART packet.

3.6.4.3 Start Bit

The UART data transmission line is normally held at a high voltage level when it's not transmitting data. To start the transfer of data, the transmitting UART pulls the transmission line

from high too low for one (1) clock cycle [39]. When the receiving UART detects the high to low voltage transition, it begins reading the bits in the data frame at the frequency of the baud rate.

3.6.4.4 Data Frame

The data frame contains the actual data being transferred. It can be five (5) bits up to eight (8) bits long if a parity bit is used. If no parity bit is used, the data frame can be nine (9) bits long. In most cases, the data is sent with the least significant bit first.

3.6.4.5 Parity

Parity describes the evenness or oddness of a number. The parity bit is a way for the receiving UART to tell if any data has changed during transmission. Electromagnetic radiation, mismatched baud rates, or long distance data transfers can change bits.

After the receiving UART reads the data frame, it counts the number of bits with a value of 1 and checks if the total is an even or odd number. If the parity bit is a 0 (even parity), the 1 or logic-high bit in the data frame should total to an even number. If the parity bit is a 1 (odd parity), the 1 bit or logic highs in the data frame should total to an odd number.

When the parity bit matches the data, the UART knows that the transmission was free of errors. But if the parity bit is a 0, and the total is odd, or the parity bit is a 1, and the total is even, the UART knows that bits in the data frame have changed.

3.6.4.6 Stop Bits

To signal the end of the data packet, the sending UART drives the data transmission line from a low voltage to a high voltage for one (1) to two (2) bit(s) duration.

3.6.5 Integration of the UART Communication in the System:

3.4.5.1 Initialization and Setup

Upon system startup, the ESP32 initializes its UART interface to establish communication with the ESP8266. This involves configuring the baud rate, data bits, stop bits, and parity settings to match those of the ESP8266. The configuration involve a baud rate of 115200 bps, 8 data bits, 1 stop bit, and no parity. Both devices need to be configured with matching settings to ensure reliable data transfer.

3.6.5.2 Data Transmission

The ESP32 collects sensor data from the end nodes and stores it on the SD card. At regular intervals, typically every 10 minutes, the ESP32 prepares to transmit this data to the ESP8266 for uploading to the Firebase dataset. The ESP32 reads the stored data from the SD card and formats it into packets suitable for UART transmission. Each packet includes data such as timestamps, sensor readings, and node identifiers.

The ESP32 sends these data packets to the ESP8266 via the UART interface. The ESP8266, upon receiving the data packets, processes them and establishes a connection to the Firebase server over Wi-Fi. It then uploads the data, ensuring that the hosted website is updated with the latest measurements.

3.7 The monitoring methods used in the system

3.7.1 The External Website

The external website is a comprehensive interface built using HTML for structure, CSS for styling, and JavaScript for dynamic content. The server side is powered by Node.js, which manages data requests and interactions with Firebase.

3.7.1.1 Google Firebase

Firebase is a product of Google, which helps developers to build, manage, and grow their apps easily. It helps developers to build their apps faster and in a more secure way. No programming is required on the firebase side, which makes it easy to use its features more efficiently. It provides services to android, iOS, web, and unity. It provides cloud storage. It uses NoSQL for the database for the storage of data.

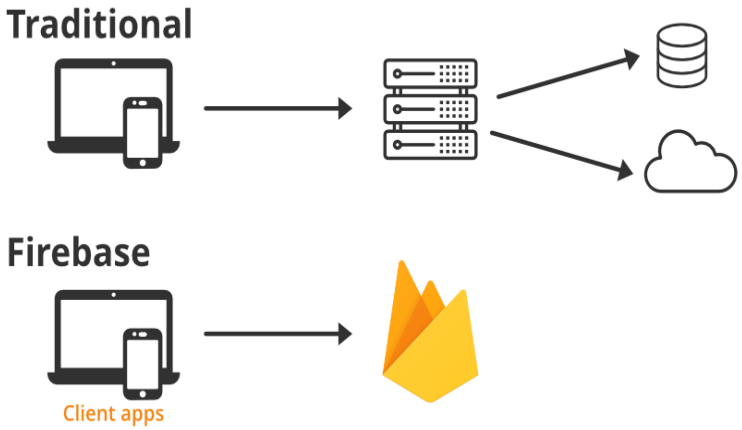


Figure III 10- Firebase Working Principal

3.7.1.2 Features of Firebase

Mainly there are three categories in which firebase provides its services.

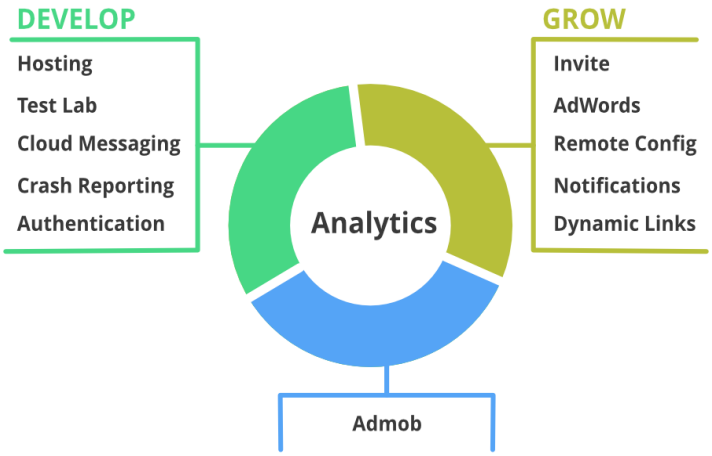


Figure III 11- firebase features

3.7.1.2.1 Build better applications

This feature mainly includes backend services that help developers to build and manage their applications in a better way. Services included under this feature are:

3.7.1.2.2 Real-time Database:

The Firebase Real-time Database is a cloud-based NoSQL database that manages your data at the blazing speed of milliseconds. In simplest terms, it can be considered as a big JSON file

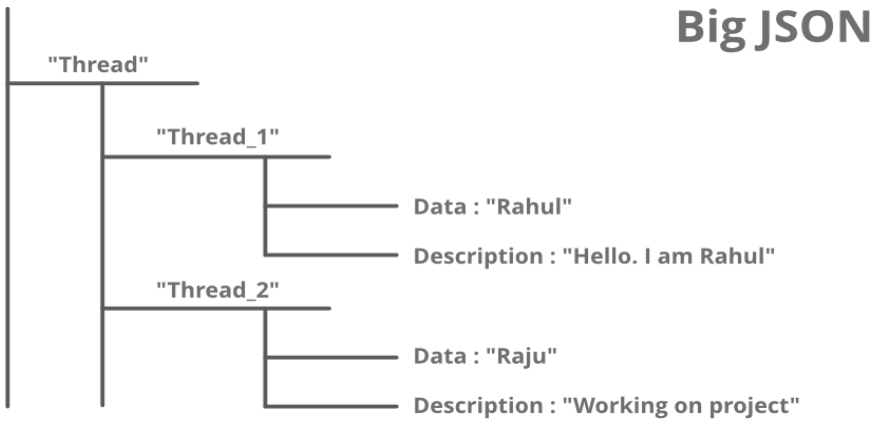


Figure III 12- Big JSON structure explanation

3.7.1.2.3 Cloud Fire store:

The cloud Fire store is a NoSQL document database that provides services like store, sync, and query through the application on a global scale. It stores data in the form of objects also known as Documents. It has a key-value pair and can store all kinds of data like, strings, binary data, and even JSON trees

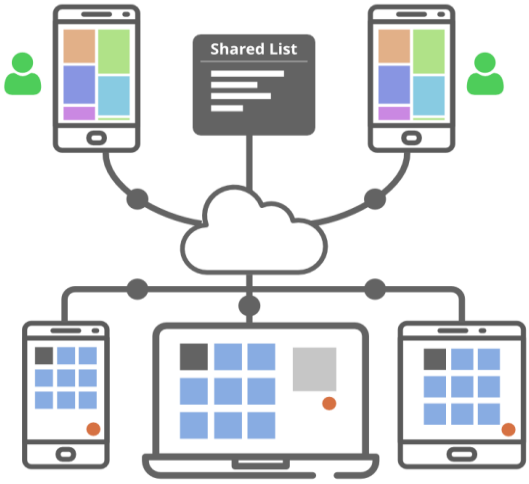


Figure III 13- Cloud fire store

3.7.1.2.1 Authentication:

Firebase Authentication service provides easy to use UI libraries and SDKs to authenticate users to your app. It reduces the manpower and effort required to develop and maintain the user authentication service. It even handles tasks like merging accounts, which if done manually can be hectic.

3.7.1.2.1 Remote Config:

The remote configuration service helps in publishing updates to the user immediately. The changes can range from changing components of the UI to changing the behaviour of thapplications. These are often used while publishing seasonal offers and contents to the application that has a limited life .

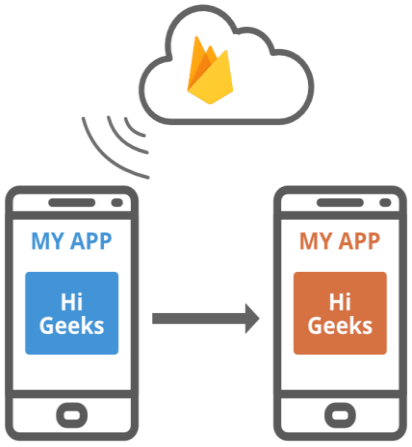


Figure III 14- Firebase Remote config

3.7.1.2.1 Hosting:

Firebase provides hosting of applications with speed and security. It can be used to host Static or Dynamic websites and micro services. It has the capability of hosting an application with a single command.

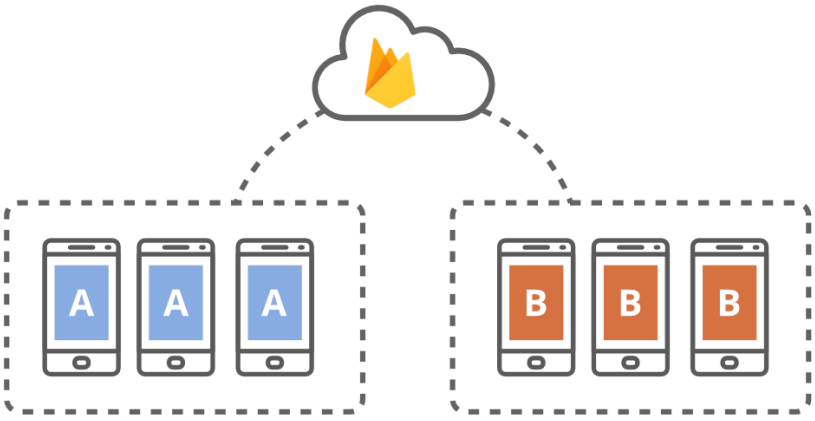


Figure III 15- Firebase Hosting remote config

Firebase Cloud Messaging (FCM): The FCM service provides a connection between the server and the application end users, which can be used to receive and send messages and notifications. These connections are reliable and battery-efficient.

3.7.1.2 HTML (Hypertext Markup Language)

HTML is the standard markup language used to create the structure of web pages. It defines the elements such as headings, paragraphs, links, images, and forms. In our project:

- HTML forms the backbone of the web interface, defining the layout and structure of the data presentation.
- Elements like tables and charts for displaying sensor data are structured using HTML.
- HTML tags are used to integrate scripts and styles, ensuring that the content is well organized and accessible.

3.7.1.3 CSS (Cascading Style Sheets)

CSS is used to control the presentation and layout of web pages. It allows us to style HTML elements with colors, fonts, spacing, and positioning. In our project:

- CSS ensures the website is visually appealing and user-friendly.
- Responsive design techniques in CSS make the website accessible on various devices, from desktops to smartphones.
- CSS frameworks like Bootstrap can be used to simplify the styling process and ensure a consistent look and feel across the website.

3.7.1.4 JavaScript

JavaScript is a scripting language used to create dynamic and interactive content on web pages. It allows us to manipulate HTML and CSS, handle events, and interact with external services. In our project:

- JavaScript fetches real-time data from Firebase and updates the web page without requiring a full reload, enhancing the user experience.
- Libraries like Chart.js or D3.js are used to create interactive charts and graphs that visualize the sensor data.
- JavaScript handles user interactions, such as setting alerts for specific water quality parameters.

3.7.1.5 Node.js

Node.js is a runtime environment that allows JavaScript to be executed on the server side. It is built on Chrome's V8 JavaScript engine and is designed to build scalable network applications. In our project:

- **Node.js** handles the backend logic, managing data requests, and interactions with Firebase. It provides a fast, efficient way to handle multiple concurrent connections with minimal overhead.
- **Express.js**, a web application framework for Node.js, simplifies the creation of robust and scalable web applications. It handles routing, middleware, and server-side logic, making it easier to build the backend of our external website.
- Node.js, combined with Firebase, allows real-time synchronization of data between the server and client, ensuring users always have access to the latest sensor readings.

3.7.2 In-Depth Overview of the External Website

The external website is a comprehensive interface built using HTML for structure, CSS for styling, and JavaScript for dynamic content. The server side is powered by Node.js, which manages data requests and interactions with Firebase.

- **HTML** provides the framework for the website, defining various sections such as the dashboard, data visualization panels, and user settings.
- **CSS** enhances the visual appeal and usability of the website, ensuring it is responsive and visually consistent.

- **JavaScript** adds interactivity, enabling real-time data updates and user settings management.
- **Node.js** manages backend operations, ensuring seamless data flow between the website and Firebase.

3.7.2.1 Real-Time Data Sync with Firebase

Sensor data from the ESP-12 module is periodically uploaded to the Firebase Real-time Database. The Node.js server maintains a continuous sync with Firebase, ensuring that the external website always displays the most recent data.

- **Firebase Real-time Database:** Ensures immediate data availability and synchronization across all connected clients.
- **Node.js:** Handles backend logic, fetching data from Firebase and serving it to the front-end.

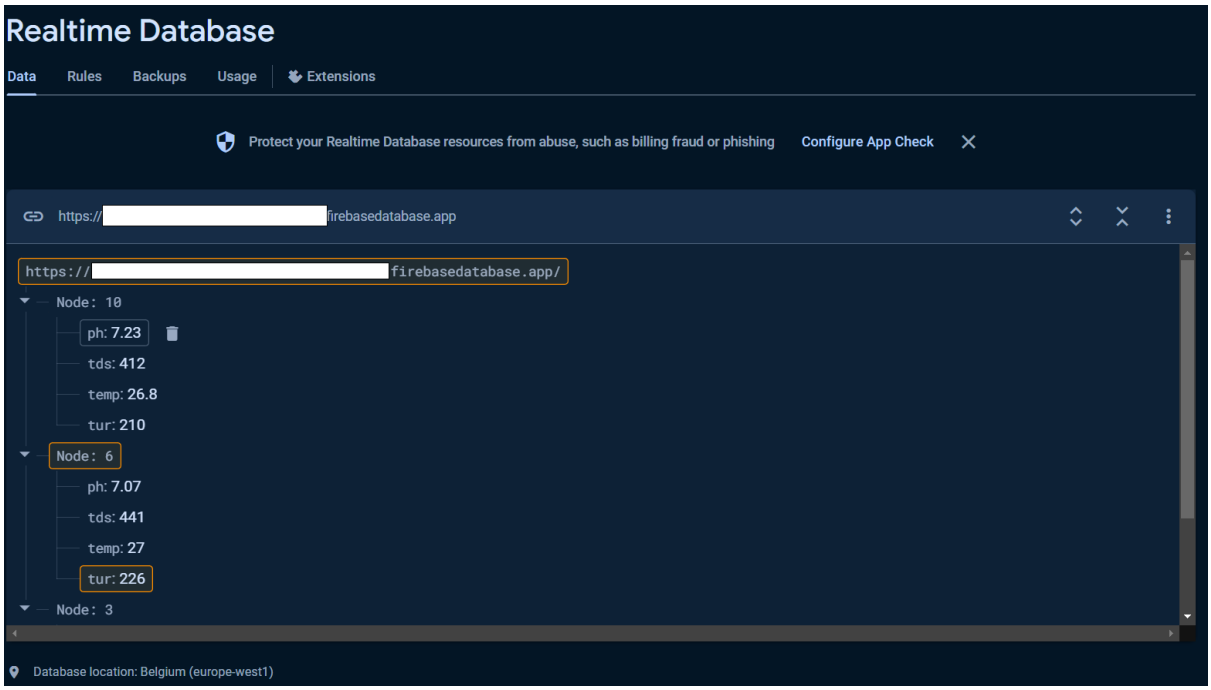


Figure III 16- Firebase real time data sync Interface

3.7.2.2 User Interface and Data Visualization

The external website features an intuitive user interface that displays real-time water quality data.

- **Real-Time Data Display**: Each sensor's readings are shown in dedicated sections, grouped by nodes, providing a clear view of the water quality parameters like temperature, pH, dissolved oxygen, turbidity, and conductivity.
- **Separation by Nodes**: Data from different nodes (secondary ESP-32 modules) is organized separately, allowing users to easily identify and compare readings from various locations.

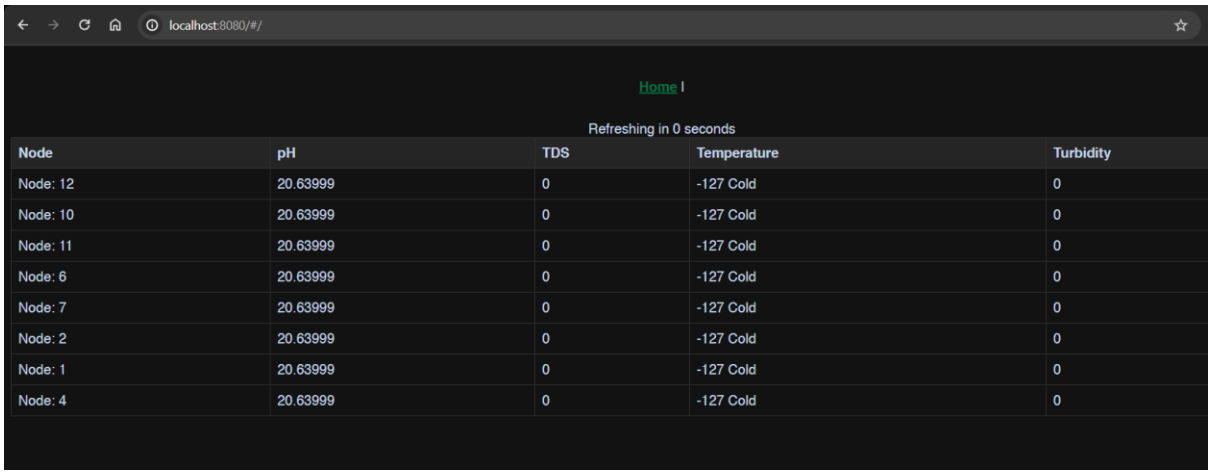


Figure III 17- Online Webserver Interface

3.7.2.3 User Authentication and Security

To ensure secure access, the external website uses Firebase Authentication for user management. This service provides multiple authentication options; ensuring only authorized users can access the system.

- **Firebase Authentication:** Manages user login and permissions, supporting various authentication methods.
- **HTTPS:** Ensures secure data transmission, protecting user privacy and data integrity.

3.7.2.4 Data Storage and Analysis

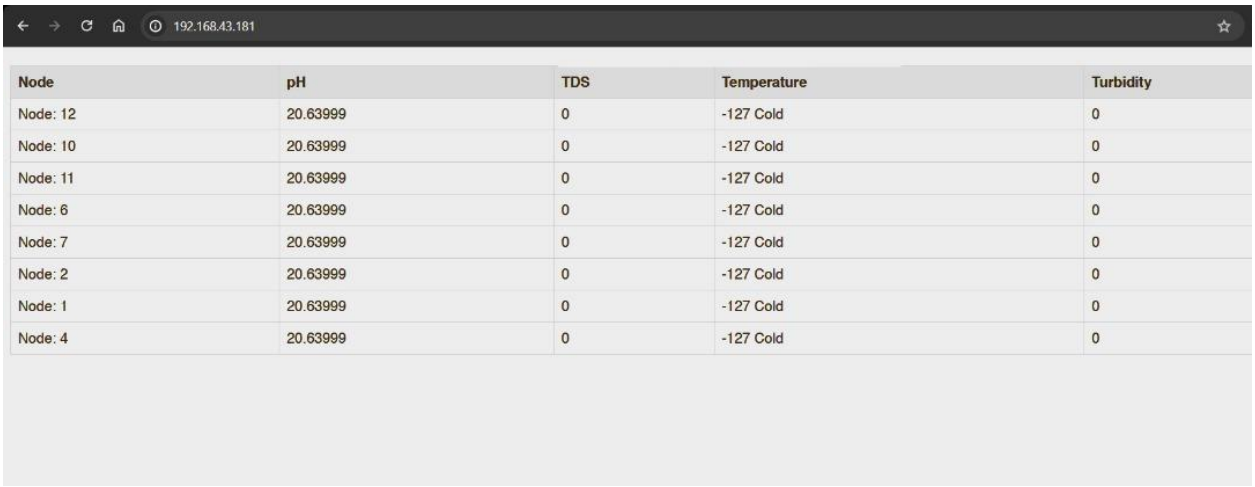
Sensor data is stored in Firebase for long-term analysis. Users can download historical data for offline analysis and use advanced analytics to gain deeper insights.

- **Historical Data**: Accessible through the website, allowing users to download and analyse past data.
- **Advanced Analytics**: Machine-learning models can be integrated to provide trend prediction and anomaly detection, enhancing water quality management.

3.7.3 The local hosted Website

The ESP-12 microcontroller hosts a local website that provides real-time access to sensor data. This website is accessible within the local network, allowing direct monitoring of water quality parameters. The ESP8266 runs a lightweight web server using its built-in Wi-Fi capabilities. This web server serves HTML, CSS, and JavaScript files, which form the front-end of the local website. The user interface is designed to be intuitive, displaying real-time data for temperature, pH, dissolved oxygen, turbidity, and conductivity.

The ESP8266 collects data from various sensors connected to the secondary nodes, typically ESP-32 modules. This data is processed and updated on the local website in real-time. Each measurement is displayed in a manner that distinguishes data from different nodes, ensuring that every node's specific reading for pH, temperature, conductivity, and other parameters are clearly presented. Access to the local website is available through a web browser on any device connected to the same local network as the ESP8266 module.



Node	pH	TDS	Temperature	Turbidity
Node: 12	20.63999	0	-127 Cold	0
Node: 10	20.63999	0	-127 Cold	0
Node: 11	20.63999	0	-127 Cold	0
Node: 6	20.63999	0	-127 Cold	0
Node: 7	20.63999	0	-127 Cold	0
Node: 2	20.63999	0	-127 Cold	0
Node: 1	20.63999	0	-127 Cold	0
Node: 4	20.63999	0	-127 Cold	0

Figure III 18- Local webserver client

This direct access ensures continuous monitoring of water quality parameters without needing an internet connection, providing immediate and local insights into the system's status. By displaying each node's data individually, the system allows for precise monitoring and management of multiple sensors and locations within the tilapia farm, enhancing the overall effectiveness of the water quality monitoring system.

3.8 Sensor calibration:

3.8.1 turbidity sensor calibration

Accurate monitoring of water quality is crucial in various applications, including aquaculture. One of the key parameters in assessing water quality is turbidity, which indicates the clarity of water. Proper calibration of turbidity sensors ensures reliable measurements, which are essential for maintaining optimal conditions in aquaculture systems, such as tilapia farming. This section details the linear calibration process of a turbidity sensor to achieve precise turbidity readings.

Linear sensor calibration is the process of adjusting and validating the output of a sensor to ensure that it accurately reflects the measured physical parameter. This involves comparing the sensor's output to known standards and applying corrections to align the sensor's readings with the true

values. The goal is to establish a linear relationship between the sensor output and the actual measurement, which can be expressed mathematically as a linear equation. For our turbidity sensor, we used distilled water with a turbidity of 0 NTU and very dirty water with a turbidity of 100 NTU as reference points.



Figure III 19- Water samples used with Turbidity sensor

Table III 1- Turbidity sensor calibration

	Turbidity value (NTU)	**Output voltage**
Clean water	**0**	**1.8**
Dirty water	**100**	**0**

3.8.1.1 Performing Linear Regression

We apply linear regression to these data points to find the line of best fit. The resulting equation will have the form $\boldsymbol{V = m \times turbidity + b}$ **(8)**

3.8.1.2 Deriving the Linear Equation

Using the points (0, 1.8) and (100, 0), we calculate the slope m and intercept b

$$\boldsymbol{m = \frac{V2 - V1}{turbidity2 - turbdity\,1} = -0.018} \quad \textbf{(9)}$$

$$\boldsymbol{b = V1 - m \times turbdity1 = 1.8} \quad \textbf{(10)}$$

So, the equation is:

$$V = -0.018 \times turbidity + 1.8 \quad (11)$$

After finding the slope m and intercept b we implement them directly in the code the slope m and intercept b

3.8.2 The ph sensor calibration

3.8.2.1 Calibration of The PH-4502

The calibration method for the PH-4502 sensor board with the ESP32 involves setting an appropriate voltage offset to ensure accurate pH measurements. Typically, the sensor board outputs a voltage corresponding to the pH value, where a pH of 0 represents 0V and a pH of 14 represents 5V. However, by default, the board is configured such that a pH of 7 results in a voltage near 0V, which can differ slightly due to variations between pH probes. This configuration poses a challenge, as voltages for acidic pH values (below 7) may become negative, which the ESP32 analog input cannot read. To resolve this, the offset potentiometer on the sensor board, located near the BNC connector, is adjusted so that a pH of 7 outputs a voltage of 2.5V. This adjustment allows the analog pin to accurately read voltages from 0V to 5V, covering the entire pH range. The calibration process involves disconnecting the pH probe and short-circuiting the BNC connector to simulate a neutral pH of 7. This can be done by stripping both ends of a wire, wrapping one end around the outside of the BNC connector, and inserting the other end into the BNC hole.



Figure III 20- Short-circuiting the BNC connector

3.8.2.2 Probe calibration

For the calibration of the pH-4502 sensor probe with the ESP32, we utilized three pre-made buffer solutions with pH values of 4.14, 6.85, and 9.98, prepared from buffer powder.



Figure III 21- Pre made buffer solution

These solutions provided reference points across the pH spectrum. Calibration was conducted at three different temperatures: 26°C to account for the temperature sensitivity of pH measurements. The calibration process involved immersing the probe in each buffer solution and recording the corresponding voltage output at each temperature. These are measurements we obtained

Table III 2- Measurement on 26 temperature

solution	v	base 1	2	3
PH Labo	ph	4.14	6.85	8.98
pH 1	3.3	3.23v	2.65v	2.25v
	5	3.17v	2.72v	2.26v
ph2 s	3.3	3.19 v	2.68v	2.28v
	5	3.15v	2.69v	2.26v
Temp labo	26.6			
temp ds	26.56			

Table III 3- Mesurment on 40.8 temprature

solution	v	base 1	2	3
PH Labo	ph	4.02	6.91	9.03
pH 1	3.3	3.19v	2.75	2.3
	5	3.18v	2.74	2.32
ph2	3.3	3.18v	2.65	2.17
	5	3.17v	2.68	2.16
Temp labo	40.8			
temp ds	41			

Table III 4- Mesurment on 46.8 temprature

solution	v	base 1	2	3
PH Labo	ph	4.03	6.92	9.01
pH 1	3.3	3.19	2.73	2.32
	5	3.18	2.82	2.33
ph2	3.3	3.18	2.6	2.15
	5	3.17	2.56	2.16
Temp labo	46.8			
temp ds	47.19			

3.8.2.3 Performing Linear Regression

We apply linear regression to these data points to find the line of best fit. The resulting equation will have the form $\boldsymbol{V = m \times PHvalue + b}$ **(12)**

3.8.2.4 Deriving the Linear Equation

Using the points (4.14, 3.23) and (6.85, 2.65), (8.98, 2.25) we calculate the slope m and intercept b and we found

$$\boldsymbol{V = -0.1294 \times PHvalue + 3.76} \quad \textbf{(13)}$$

After finding the slope m and intercept b we implement them directly in the code the slope m and intercept b

3.9 Testing and Analysis of Tilapia water Monitoring System

To test our water quality monitoring system, we conducted an experiment at an aquaculture tilapia farm in our state, Medea, specifically in Ben Chicao. We applied our tests in three different tilapia pools as per the farm owner's guidance. Two of the pools were reported to be in good condition, while the third pool was in decent, though not bad, condition



Figure III 22- Pools state representations.

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The system was launched for a duration of two hours and half , with measurements being recorded every 15 minutes. The turbidity values were not included in the data analysis since they consistently showed the same readings throughout the measurement period. This consistency was attributed to the recent change of pool water, resulting in minimal variation in turbidity levels. Here are the results recorded during the measurement period:

Table III 5- Measures test in the field

Time	Pool 1 temperature	Pool 2 temperature	Pool 3 temperature	Pool 1 Ph	Pool 2 Ph	Pool 3 Ph	pool 1 tds(ppm)	Pool 2 tds (ppm)	Pool 3 tds(ppm)
10:00	25.1	25.3	24.8	7.21	7.19	7.01	196.4	198	198
10:15	25.0	25.2	24.9	7.36	7.29	7.10	190.4	200	191.5
10:30	25.2	25.4	24.4	7.24	7.18	7.01	198.1	191	191.1
10:45	25.1	25.3	24.8	7.28	7.17	7.05	192.5	193	193
11:00	25.0	25.2	24.9	7.31	7.28	7.14	200.0	194.0	194.0
11:15	25.2	25.4	24.7	7.28	7.19	7.01	194.6	199.1	196.1
11:30	25.1	25.3	24.8	7.29	7.18	7.01	198.1	199.4	195.4
11:45	25.0	25.2	24.9	7.32	7.28	7.11	191.0	197.1	197.1
12:00	25.2	25.4	24.7	7.27	7.19	7.00	199.5	198.5	191.5
12:15	25.1	25.3	24.8	7.28	7.19	7.02	197.3	200.0	198.0
12:30	25.0	25.2	24.9	7.33	7.29	7.14	199.5	199.0	197.0

3.9.1 pH Analysis

The pH levels across all three tilapia pools remained stable throughout the three-hour monitoring period. Pool 1 and Pool 2 consistently maintained pH levels between 7.2 to 7.3, indicative of slightly alkaline conditions suitable for tilapia. In contrast, Pool 3 showed slightly lower pH levels ranging from 7.0 to 7.15, which still fall within acceptable ranges for aquaculture. The stable pH readings indicate that the water conditions were conducive to fish health and growth during the experiment.

3.9.2 Temperature Analysis

Temperature variations were minimal among the three pools during the monitoring period. Pool 1 recorded temperatures between 25.0°C to 25.2°C, while Pool 2 ranged from 25.2°C to 25.4°C. Pool 3 exhibited slightly lower temperatures, fluctuating between 24.7°C to 24.9°C. These temperature ranges are optimal for tilapia farming, ensuring that the water remains within the species' preferred temperature range for growth and metabolism. The stable temperature readings indicate that the thermal conditions in all pools were well maintained and suitable for aquaculture purposes.

3.9.3 TDS Analysis

Total Dissolved Solids (TDS) measurements showed consistent values across the three pools, albeit with some variability. Pool 1 and Pool 2 consistently registered TDS levels between 191 to 200 ppm, indicating good water quality with a balanced concentration of dissolved salts and minerals. Pool 3, while still within acceptable limits, showed slightly lower TDS values ranging from 191 to 198 ppm. It's important to note that these TDS measurements were approximate due to the sensor not being fully calibrated, which may have affected the precision of the readings. Nonetheless, the consistent TDS levels suggest that the water quality remained stable and suitable for tilapia health and growth throughout the experiment.

3.10 Conclusion

The tilapia monitoring system offers significant benefits in enhancing aquaculture management practices through real-time data monitoring. By employing a robust Wi-Fi mesh network between nodes, the system ensures seamless communication and data synchronization across the farm. This infrastructure supports efficient data collection from sensors measuring pH, temperature, conductivity, turbidity, at multiple points within the pond environment.

The integration of a local website and server further enhances the system's utility by providing accessible, real-time insights into water quality parameters. Users can conveniently monitor and analyze data directly within the local network, facilitating prompt decision-making and proactive management of the tilapia farm. This approach not only improves operational efficiency but also contributes to maintaining optimal conditions for tilapia growth and health.

General Conclusion

In this Thesis project, we have targeted Aquaculture farms that raise Tilapia and addressed one of their problems which is water quality, water quality degradation can lead to severe consequences such as the mortality of fish which causes a considerable loss, even without the mortality, the outcome of Fish growth would be substantially lower.

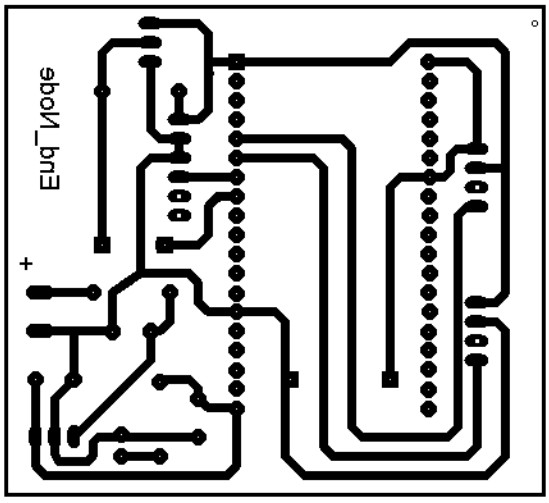
We had designed a solution specifically for these farms, an IoT project powered by multiple ESP32 SoCs connected together using WiFi mesh, trading information from one to another reaching a sink node which delivers the real-time information to the farm owner through a web server accessible anytime and anywhere in the world.

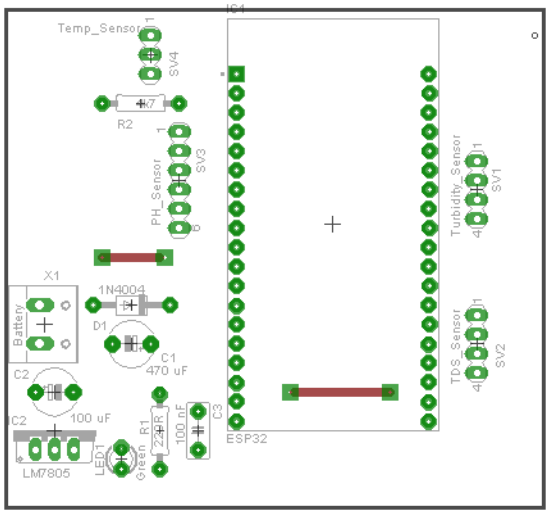
We have carefully chosen our used sensors to work in harmony, well calibrated to industrial standards in order to deliver the most accurate results, they were programmed to work simultaneously to deliver real time data, the sensors measurements have given promising results comparing to standard measurements methods in the industry.

The final data is to be distributed into our real-time data base and saved to the SD card at the same time for later usage and statistics and notify the farmer in case of any severe situation.

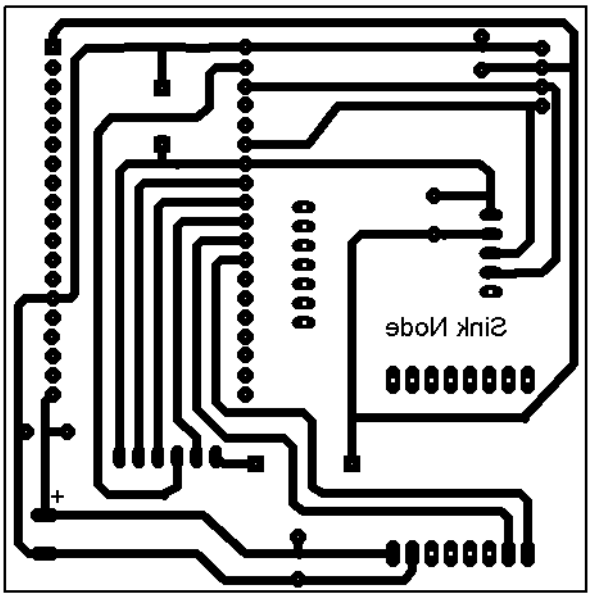
Annexe

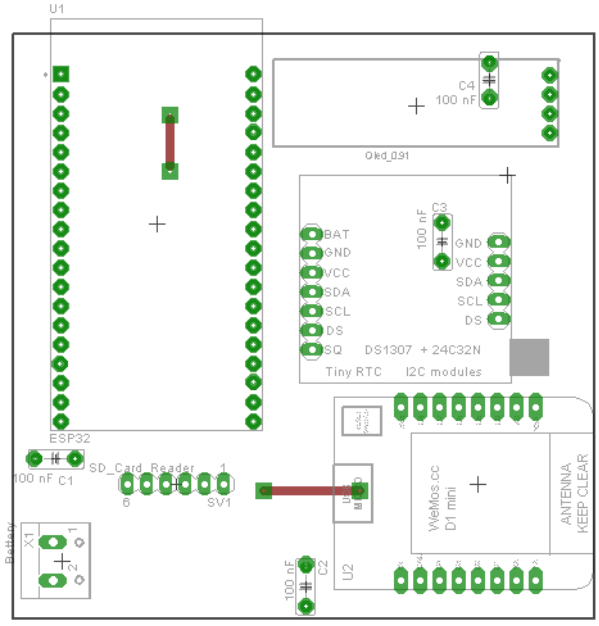
End node PCB / Circuit





Sink node PCB / Circuit





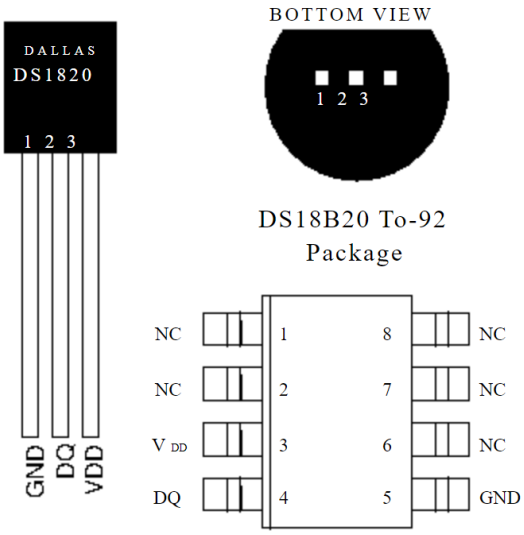
Annexe 2

Data sheet of temperature sensor

FEATURES

- Unique 1-Wire interface requires only one port pin for communication
- Multidrop capability simplifies distributed temperature sensing applications
- Requires no external components
- Can be powered from data line. Power supply range is 3.0V to 5.5V
- Zero standby power required
- Measures temperatures from -55°C to +125°C. Fahrenheit equivalent is -67°F to +257°F
- ±0.5°C accuracy from -10°C to +85°C
- Thermometer resolution is programmable from 9 to 12 bits
- Converts 12-bit temperature to digital word in 750 ms (max.)
- User-definable, nonvolatile temperature alarm settings
- Alarm search command identifies and addresses devices whose temperature is outside of programmed limits (temperature alarm condition)
- Applications include thermostatic controls, industrial systems, consumer products, thermometers, or any thermally sensitive system

PIN ASSIGNMENT



DS18B20 To-92 Package

DS18B20Z
8-Pin SOIC (150 mil)

PIN DESCRIPTION

GND - Ground
DQ - Data In/Out
V_{DD} - Power Supply Voltage
NC - No Connect

DESCRIPTION

The DS18B20 Digital Thermometer provides 9 to 12-bit (configurable) temperature readings which indicate the temperature of the device.

Information is sent to/from the DS18B20 over a 1-Wire interface, so that only one wire (and ground) needs to be connected from a central microprocessor to a DS18B20. Power for reading, writing, and performing temperature conversions can be derived from the data line itself with no need for an external power source.

Because each DS18B20 contains a unique silicon serial number, multiple DS18B20s can exist on the same 1-Wire bus. This allows for placing temperature sensors in many different places. Applications where this feature is useful include HVAC environmental controls, sensing temperatures inside buildings, equipment or machinery, and process monitoring and control.

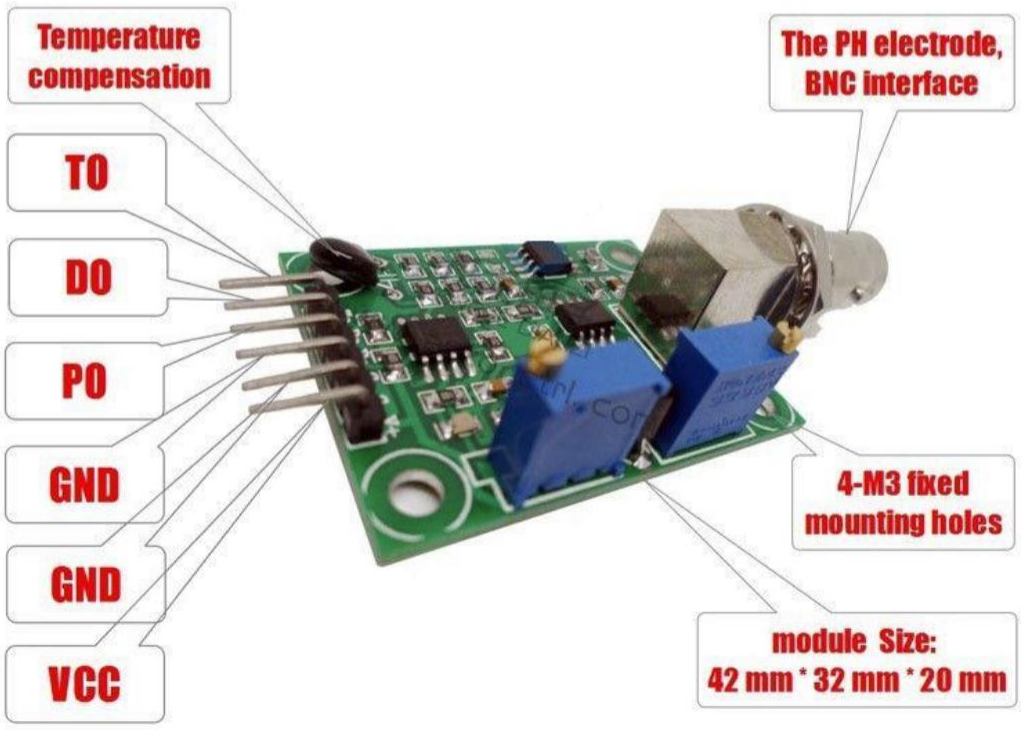
Data sheet of ph module sensor

If you worked with PH metering before you will know that PH values range from 0-14. Where PH 0 Will be very acidic, PH 7 will be neutral and PH 14 very alkaline. Water is near a PH 7 and this is usually around here that we will need to monitor PH of many things. A swimming pool, for example, should be slightly alkaline at 7.2, hydroponics systems around 6 (for optimum plant nutrition takeup) and aquaponics around 6.8.

I wrote this **PH probe and sensor** "how to" because it is not as straightforward as one would think (but quite easy when you understand the ins and outs) mostly because there is not a lot of information on this on the Internet, surely not detailed information.

We will first look at the ph probe module board and then the PH probe because both the PH probe and sensor have to be set correctly:

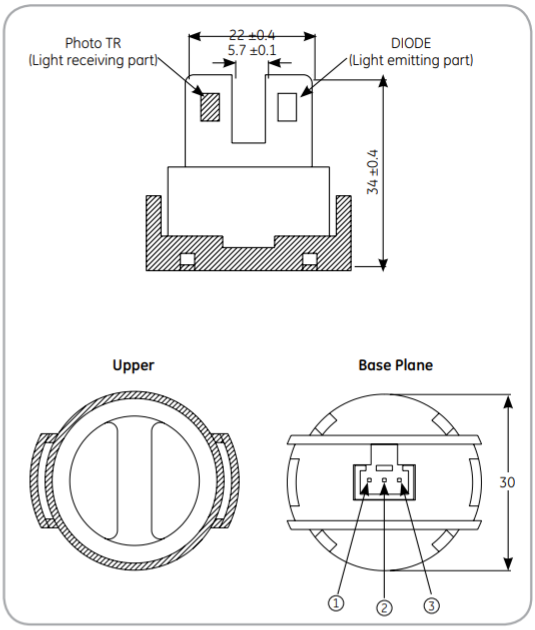
- offset setting
- limit setting
- sketch to test the board analogue range
- sketch for PH reading and calibration.
- calibration of PH probe
- PH probe usage
  The ph probe module in this tutorial is available on our site here: PH probe module BNC conector

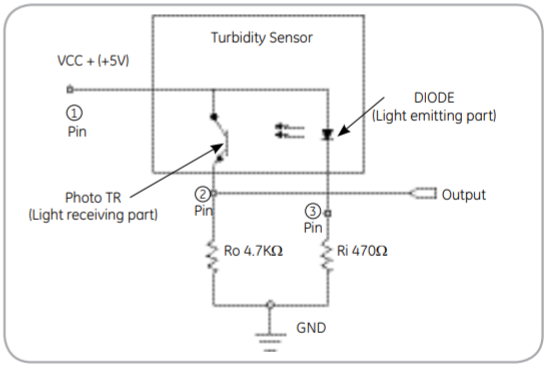


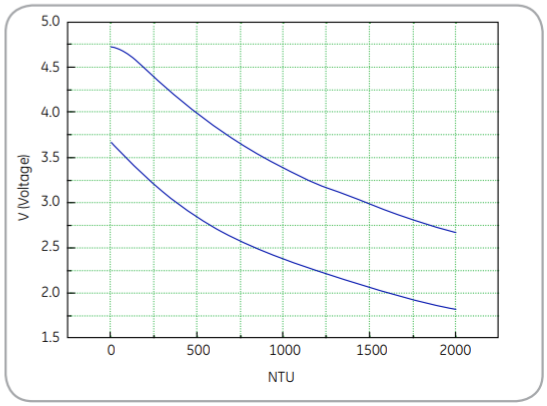
turbidity sensor data sheet

Theory of Operation

The sensor operates on the principle that when light is passed through a sample of water, the amount of light transmitted through the sample is dependent on the amount of soil in the water. As the soil level increases, the amount of transmitted light decreases. The turbidity sensor measures the amount of transmitted light to determine the turbidity of the wash water. These turbidity measurements are supplied to the washer controller, which makes decisions on how long to wash in all the cycles. These decisions are made based on a comparison between clean water measurements (taken at the beginning of the wash cycle) and the wash water turbidity measurement taken at the end of each wash cycle. By measuring the turbidity of the wash water, the washing machine can conserve energy on lightly soiled loads by only washing as long as necessary. This will result in energy savings for the consumer.







Specifications

Part Number
TSW-10

Rated Voltage
DC 5V (between No #1 & Ground)

Voltage Differential
1.3V ± 20%

Test Method
After testing voltage in water (0 NTU),
voltage test in water (1000 NTU)
(Turbidity level Calibration -> Master NTU standard liquid)
(Voltage between No #2 pin & Ground)

Operating Temperature Range
-30°C ~ 80°C

Storage Temperature Range
-10°C~ 80°C

Rated Current
Max. 30 mA

Insulation Resistance
Min 100 MΩ by 500V DC

Application Section
Detecting the turbidity degree of water

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