CHAPTER 1. INTRODUCTION

1.1 Project Background

Betta splendens or Siamese fighting fish are indigenous to the shallow slow water in Southeast Asia. The aggressive nature and selection of a huge variety of colors and fin shapes has been developed over years to breed them (Lichak et al., 2022). They live in aquarium since they can breathe air through a special organ called a labyrinth. To ensure good health in these fish, it is necessary to provide them with clean water that is stable (Lichak et al., 2022). They are able to survive in varying conditions, but living in bad water too long may cause sickness, so it is highly significant to regulate the quality of water (Lichak et al., 2022).

In addition to this, experimental research of the Betta splendens has also shown that nitrogenous waste products in closed systems, especially ammonia and nitrite, may become highly concentrated and have negative effects on physiology when fish are kept in small amounts of water and water chemistry is not properly controlled (Kajimura et al., 2023). They show that ammonia and nitrite are relatively tolerable by bettas compared to some other freshwater species, but in the conditions of high external loads, plasma ammonia and nitrite concentrations also enhance, and there are also changes in blood parameters that indicate physiological stress (Kajimura et al., 2023). These results, which were acquired in laboratory conditions, may indicate that the confinement in small containers unless supported by effective waste management and water renewal will result in the gradual lowering of the quality of water that even a relatively resilient species finds hard to tolerate (Kajimura et al., 2023).

Water quality plays an important role in aquaculture, as wastes and chemical imbalances can lead to disease and reduced productivity due to the need to manage water quality and maintain the environment (Flores-Iwasaki et al., 2025). The traditional tools such as manual sampling and laboratory tests are time-consuming and can only create a few snapshots, and it is difficult to observe rapid or minor changes in the state of water (Flores-Iwasaki et al., 2025). Due to that fact, there is

the interest in applying continuous and automated monitoring to improve water quality management in aquaculture systems (Flores-Iwasaki et al., 2025).

The current IoT technologies in aquaculture apply sensors, local processing, and communication networks to continuously monitor the water quality (Flores-Iwasaki et al., 2025). These systems transmit sensor data to microcontrollers or servers where the sensor data can be viewed, stored and analyzed in real time. It assists in monitoring tendencies, identifying issues, and remote monitoring is possible (Flores-Iwasaki et al., 2025). It is revealed that the IoT-based monitoring can assist managers in making healthier decisions, react more quickly to water quality concerns, and in some cases, lower the death of fish and enhance their growth (Flores-Iwasaki et al., 2025).

Considering these developments, developing an IoT based monitoring of water quality and automatic replacement of water in aquariums with Betta splendens will utilise the well-established concepts in large-scale aquaculture to smaller tanks. The proposed project is expected to minimize risks associated with waste accumulation and fluctuating water quality in small tanks as demonstrated in the literature and care recommendations through the application of the modern sensors and communication devices to maintain the conditions constant with the course of time.

1.2 Problem Statement

Referring to the background described above, this final project addresses the following problems:

It is necessary to maintain the water quality constant in order to maintain the health and well-being of betta fish (Lichak et al., 2022). Nevertheless, a lot of aquarium owners use manual inspection and non-systematic maintenance, which is based on their time and experience. The alteration in temperature, pH or dissolved solids proceeds very slowly and is usually not noticed until the fish develops the symptoms of stress or sickness when the water may already be contaminated.

Making time and regular effort, manual monitoring with the help of test kits or handheld devices is likely to be neglected during the hectic everyday life.

Likewise, water replacement is usually postponed or done in an irregular manner, which further endangers the occurrence of chronic stress, compounded water quality decline in small aquarium systems, which subsequently raises disease vulnerability in betta fish (Lichak et al., 2022). The absence of constant feedback also prevents the hobbyists to react to sudden changes in the environment as well as to test the efficiency of the corrective measures and, to this end, the creation of IoT-based, non-manual water quality monitoring systems in aquaculture has been driven by this limitation (Inas Fikri et al., 2021); (Flores-Iwasaki et al., 2025).

Though different systems of IoT-based aquarium and water quality monitoring have been offered, the majority of currently operational systems concentrate on sensing and providing notifications to users instead of taking corrective measures (Flores-Iwasaki et al., 2025). They are also typically a combination of sensors and microcontrollers to measure different parameters like temperature, pH and turbidity and use dashboards or mobile apps to notify the user when the parameters are out of range (Flores-Iwasaki et al., 2025). Nonetheless, water replacement and corrective intervention are usually left to the user, and most reported systems are optimized to the overall requirements of aquaculture in general and large tanks, but not the particular requirements of small-volume betta aquariums used by home hobbyists. Available automation prototypes with water-change functions tend to provide simple displacement of water, however, they do not involve comprehensive and multi-parameter monitoring and automatic replacement based on the requirements of betta fish. The given gap shows that there is a need to consider a comprehensive IoT-based solution that will integrate real-time water quality monitoring with automatic and threshold-based water replacement designed to specifically serve betta aquariums.

1.3 Project Objectives

The main objective of this project is to design and develop an IoT-based system that continuously monitors key water quality parameters and automatically performs partial water replacement to maintain suitable conditions in betta fish aquariums.

The specific objectives are;

a. To design and implement a real-time water quality monitoring subsystem that integrates an IoT-capable microcontroller with temperature, pH, total dissolved solids, and turbidity sensors for continuous data acquisition in betta aquariums.
b. To develop an automatic, rule-based partial water replacement mechanism that is triggered when monitored parameters exceed predefined thresholds, thereby reducing reliance on manual monitoring and intervention.
c. To evaluate the performance and effectiveness of the integrated system in maintaining water quality within recommended ranges for Betta splendens, including assessment of sensor accuracy, data transmission reliability, and responsiveness of the automatic water replacement process.

1.4 Project Scope

This study aims at developing and testing an IoT-based water quality monitoring and automated partial water replacement prototype that has been specifically developed in relation to betta fish (Betta splendens) aquarium. Betta fish are chosen as they are popular ornamental species and cannot tolerate water quality conditions in the captivity (Lichak et al., 2022). They can also be usually kept in small-volume and individual tanks and hence can be applicable to small-scale IoT experimentation. The system is designed to serve small freshwater aquariums indoors which are usually used by hobbyists in the home setting; with presumed tank sizes in a narrow range of volumes. The research will be confined to single-species betta tanks having relatively simple set up with omission of aqua scaping or multi-species systems. It does not cover outdoor ponds, large aquaculture facilities, and the research of the more sophisticated biological filtration.

1.4.1 System Scope

The subsection will establish the functional boundaries of the proposed system, which will describe the key capabilities that will be introduced to the system, and those that are not within the scope of the proposed project. This is to

outline clearly what the system will do in small indoor Betta splendens aquariums and what will be left to the system.

Core Functional Scope

a. The system uses a microcontroller with the IoT capabilities as the core controller of the water quality data collection, simplified processing, and wireless transmissions.
b. It constantly measures the desired water quality parameters, i.e. temperature, pH, total dissolved solids (TDS), and turbidity, with the help of the necessary electronic sensors placed in the aquarium.
c. The IoT platform ensures real-time tracking and visualization of the data, which is received by the user through a mobile or web-based interface where a user can see the current and past water conditions readings.
d. It is also fitted with an automatic partial water replacement system whereby the system monitors certain parameters and the pumps or valves are operated to empty the aquarium of a part of its water and refill it back up to predetermined threshold ranges.

Evaluation Scope

a. System performance will be evaluated in terms of sensor accuracy for the monitored parameters.
b. The reliability of data transmission between the aquarium system and the IoT platform will be assessed under typical home network conditions.
c. The responsiveness and effectiveness of the automatic partial water replacement process will be examined, focusing on whether the system can restore water quality indicators toward desired ranges in a timely manner during controlled tests.

Out-of-Scope Functions

a. The system does not perform full tank cleaning, substrate cleaning, or comprehensive waste removal beyond partial water replacement.

b. It does not diagnose fish diseases, provide medical treatment, or make decisions regarding medication or water additives.
c. Automatic feeding, lighting control, temperature regulation via heaters or chillers, and integration with large-scale or multi-tank aquaculture management systems are explicitly excluded from the scope of this project.

1.4.2 User Scope

The target audience of this system is individual aquarium hobbyists and small scale betta keepers who keep Betta splendens in small indoor freshwater tanks. These users are expected to have simple knowledge of smartphone applications and common maintenance practices of aquariums, but not to be knowledgeable in the field of electronics, programming, and aquaculture engineering. The system is set to assist them in their day-to-day practice with constant updates on the main water quality parameters, an easy access to the reading via an IoT interface, and the automated partial water replacement in case the conditions are out of the defined limits. Under this, users are expected to install the system on a supported and compatible betta aquarium, set up simple system parameters like threshold values and replacement volumes, and understand system indicative status or warnings. Basic husbandry tasks such as feeding, regular cleaning of tanks, physical inspection of fish health and any treatment or medical choice is under the control of the user. The system does not aim at commercial aquaculture plants, public aquaria, or research laboratories, with a need of the centralized control of multiple tanks or sophisticated experimental options.

1.5 Project Significance

1.5.1 Operational significance

Operationally, this project will enhance the degree of uniform and responsive water quality control in small indoor tanks of Betta splendens aquarium. Even minor fluctuations in parameters such as temperature, pH, and nitrogen compounds that occur in such limited systems can have a negative impact on the health of fish, hence the importance of identifying and acting upon them in time. Recent reviews

of the recirculating aquaculture practice point out that an adequate and relatively constant water quality is vital to growth, survival and avoidance of stress-related issues in cultured fish and that real-time or high-frequency monitoring can assist in making more effective management decisions (Lindholm-Lehto, 2023).

1.5.2 Sustainability and SDG Relevance

From a sustainability perspective, this project addresses two mutually reinforcing Sustainable Development Goals at the micro-level. It aligns mainly with SDG 15: Life on land, especially Target 15.1 on the conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems (United Nations, 2015a). Betta splendens is a freshwater species, and proper maintenance of freshwater conditions around them directly impacts their welfare in captivity, where they are found naturally (in shallow inland tropical water bodies of Southeast Asia). A system that establishes responsible water-quality management, reduces avoidable fish deaths, and encourages more responsible freshwater species husbandry by hobbyists is consistent with the inherently sustainable use principles encompassed in this goal.

The other aims to align with SDG 9: Industry, Innovation and Infrastructure, which previously pursued the development of resilient, inclusive technological innovation (United Nations, 2015b). We take the systems designed around the IoT architecture, characterised by embedded sensors, microcontroller-based edge processing, and wireless communication, to a real-world problem with an unattainable level of automation in the domestic domain.

This project illustrates how a low-cost, hobbyist-scale example can fill the gap between passive monitoring systems and industrial-grade automation, making innovation affordable for both commercial aquaculture and casual household use. This supports SDG 9, which emphasises expanding access to and the scale of innovation at all levels of use.

1.5.3 Economic Significance

The system has economic potential of reducing indirect expenses to home aquarists and small-volume betta keepers by reducing the chances of avoidable losses due to the unnoticed water quality deterioration. The earlier research on the use of the IoT to monitor water quality in tilapia ponds indicates that manual procedures tend to be inconsistent, time-consuming, and that real-time sensing with remote access can enhance the efficiency of management, and lessen the chances of responding to the worsening conditions in a delayed manner (Erawati et al., 2025). Similarly, the applications of a smart aquarium which uses sensors, microcontroller and mobile interface show that regular diagnostic, automatic water management and alerts to the users can be integrated into a small system that is aimed at making life easier to the owners who cannot monitor their tanks all the time (Yulistiani et al., 2023).

1.5.4 Academic Significance

Academically, academically, builds upon the already-existing knowledge on the subject of the IoT-based water quality monitoring by extending the same ideas to a small ornamental aquarium with automatic partial water replacement that has only one species. Recirculating aquaculture system work and smart monitoring has been focused on scales of production, large culture units, where the aim is on intensification, reuse of water, and multifaceted treatment (Lindholm-Lehto, 2023). In comparison, the current project places the IoT-driven monitoring and control into the context of constraints and behavioral requirements of home aquarium care, which gives an adjacency use case and data set. This provides a foundation to future research studies on the relationship between fine-scale water quality dynamics and automated interventions and observed welfare indices on Betta splendens in hobbyist conditions.

1.6 Chapter Summary

This chapter discussed about the construction of an IoT-based water monitoring and automatically replacing a portion of water in small indoor Betta

splendens tanks. This technology would be needed because the betta fish is sensitive to change in the water and can easily be affected by the accumulation of waste in the small tanks. As much as they are able to cope with the bad conditions they may experience in the long run, their health may be damaged due to the poor water. Manual monitoring and changing of water are generally not consistent and therefore this project is aimed at solving these issues using the technical solution. The objectives of the project include designing a real time monitoring system, developing a rule based partial water replacement system and testing the prototype to determine whether it can assist in keeping the environment healthy which is conducive to the bettas. It focuses on individual-species and small indoor betta tanks and the project does not involve full automation, but basic monitoring and part-water changes. The chapter further clarified the reasons of why the project is important to the operations, economics, sustainability, welfare and research.