CHAPTER V

OTHER NONFUNCTIONAL REQUIREMENTS

This chapter outlines the nonfunctional requirements of HydroSense, emphasizing the quality attributes of the hardware and software components. It includes performance metrics, software and hardware quality attributes, safety, security, and testing requirements. Performance requirements focus on system efficiency, sensor data accuracy, real-time data visualization, and responsiveness under varying environmental conditions. The quality attributes section defines the criteria for evaluating system performance, while safety and security requirements address data integrity and sensor reliability. Additionally, this chapter covers the testing protocols to ensure HydroSense meets its operational and safety goals.

5.1 Performance Requirements

This section outlines the efficiency and effectiveness of the performance requirements of HydroSense, encompassing both hardware and software components. These requirements include various measurements used to evaluate system performance, aiding developers in identifying necessary improvements to ensure optimal functionality. The key features of HydroSense have been evaluated using quality attributes to measure system performance. These features include real-time water quality monitoring, data visualization, sensor data logging, and hydrology resources. The water quality monitoring feature, powered by sensors for Total Dissolved Solids (TDS), turbidity, pH, and temperature, provides real-time feedback through the web interface, while the hardware components, such as the ESP32-WROOM-32D and Arduino Uno, ensure accurate data collection and reliable transmission. Data visualization presents sensor readings in graphical formats, enabling users to track trends and anomalies efficiently. The data logging function allows users to store historical sensor data in CSV format for further analysis. The system hydrology resources feature provides users with educational materials and water management guidelines. Performance evaluations include the response time of sensor readings, accuracy and speed of data transmission from the hardware to the web application, real-time updates, and the system ability to handle continuous monitoring under varying environmental and operational conditions. The hardware is also evaluated for power efficiency, durability, and ability to sustain long-term use without compromising sensor accuracy.

The ISO/IEC 9126 [GFG2024] software quality model was used to evaluate the software aspects of HydroSense, focusing on usability, efficiency, and functionality. The usability attribute was emphasized to assess the quality of the user experience with the hydrology resources, data visualization, and water quality recommendation system. This includes evaluating the understandability, learnability, operability, and attractiveness of the web interface, ensuring users are able to interpret water quality data and access educational materials easily. The efficiency attribute examines how well the web application processes and displays sensor data, linking it to the real-time data visualization and contaminant detection features. This involves measuring the system response times, resource utilization, and compliance. Lastly, the functionality attribute was applied to evaluate the contaminant detection and water quality recommendation system, focusing on accuracy, interoperability, security, and suitability. These assessments ensure that HydroSense delivers reliable and actionable data on water quality. Table 16 shows the product features of the application and their respective software quality models, attributes, criteria, mean scores, and feature mean scores.

Product Features	Software Quality Models and Attributes	Software Quality Criteria	Mean Score	Feature Mean Score
Hydrology Resources	Usability (ISO/IEC-9126)	Understandability	100%	95%
		Learnability	100%	
		Operability	100%	
		Attractiveness	100%	
		Compliance	75.00%	
Contaminant Detection	Functionality (ISO/IEC-9126)	Accuracy	100%	95.90%
		Interoperability	100%	
		Compliance	85.71%	
Data Visualization	Efficiency (ISO/IEC-9126)	Resource Utilization	75.00%	91.67%
		Time Behavior	100%	
		Compliance	100%	
Water Quality Recommendation	Usability (ISO/IEC-9126)	Understandability	100%	95%
		Learnability	100%	
		Operability	80%	
		Compliance	100%	

Table 16. Summary of Features, Attributes, and Results in Software Quality Model.

The score results are interpreted using Table 17. In addition, the equations used to solve the scores are discussed. It allows the developers to interpret the quality attribute scores using narrative descriptions. The software quality model provides some significant benefits to standard users by specifying the effectiveness of each feature. The developers identified and provided a conclusion to each attribute score of the product features. This comprehensive evaluation ensures that users make informed decisions based on the performance of the system across various attributes.

Percentage Range	Interpretation	Interpretation Description
80.20% -100.00%	Very Good	The quality of performance of the application feature is on the desired and excellent level.
60.40% – 80.19%	Good	The quality of performance of the application is on a satisfactory level and a little improvement
40.60% – 60.39%	Average	The quality of performance of the application is on a fair level, some improvements are recommended.
20.80% – 40.59%	Poor	The quality of performance of the application feature is on the undesired level, more improvements are recommended.
1.00% – 20.79%	Very Poor	The quality of performance of the application feature is not acceptable, A re-design is highly recommended.

Table 17. Validation Testing Results Interpretation in Software Quality Model.

The ISO/IEC 30141 [ISO2018] IoT system reference architecture model was used to evaluate the hardware aspects of HydroSense, focusing on trustworthiness, architecture, and functional characteristics. Trustworthiness was assessed through availability, confidentiality, integrity, reliability, resilience, and safety, ensuring continuous uptime, secure data transmission, accurate sensor readings, and system recovery from environmental challenges. In terms of architecture, HydroSense was evaluated for composability, heterogeneity, modularity, and scalability, ensuring easy integration or replacement of sensors, compatibility among different sensor types, and the system ability to scale by adding more sensors. Functional characteristics such as accuracy, compliance, data handling, manageability, and real-time capability were also emphasized. This ensured precise water quality measurements, adherence to standards, efficient data processing, easy maintenance, and live data transmission. By applying ISO/IEC 30141, the developers ensured HydroSense is a secure and reliable IoT water monitoring solution capable of effectively handling real-world conditions. Table 18 shows the product, its characteristics, and the mean and feature mean scores.

Hardware	Characteristics of IoT Systems	Related Characteristics	Mean Score	Characteristic Mean Score
HydroSense	IoT system Trustworthiness characteristics (ISO/IEC-30141)	Availability	100.00%	97.22%
		Confidentiality	83.33%	
		Integrity	100.00%	
		Reliability	100.00%	
		Resilience	100.00%	
		Safety	100.00%	
	IoT system architecture characteristics (ISO/IEC-30141)	Heterogeneity	100.00%	91.67%
		Modularity	75.00%	
		Network Connectivity	80%	
	IoT system functional characteristics (ISO/IEC-30141)	Compliance	100.00%	95.24%
		Data Characteristics	100.00%	
		Real-time Capability	85.71%	

Table 18. Summary of the Product and Characteristic of the Hardware Quality Model.

The score results are interpreted using Table 19. the equations used to calculate the scores are discussed to allow developers to assess the quality attributes of the system quantitatively. This interpretation provides developers with narrative descriptions for each score range, helping them assess the system performance in areas like availability, confidentiality, integrity, scalability, and real-time capabilities. The ISO/IEC 30141 model used in this evaluation offers significant benefits to both developers and users by outlining the system effectiveness across its trustworthiness, architecture, and functional characteristics. Developers are able to use the table to identify and interpret the attribute scores of each characteristic, determining which areas of HydroSense excel and which require further improvements. This structured approach helps prioritize development efforts, ensuring a targeted enhancement of the system overall performance and reliability.

Percentage Range	Interpretation	Interpretation Description
80.20% -100.00%	Very Good	The system performs excellently, meeting all IoT system trustworthiness, architecture, and functional requirements effectively.
60.40% – 80.19%	Good	The system performs satisfactorily, though some minor improvements enhance performance.
40.60% – 60.39%	Average	The system meets functional requirements, but significant improvements are recommended for better performance and reliability.
20.80% – 40.59%	Poor	The system performs below expectations; improvements in several areas are necessary to meet quality standards.
1.00% – 20.79%	Very Poor	The system is inadequate, with major issues in performance and security, requiring urgent redesigns or overhauls.

Table 19. Validation Testing Results Interpretation in Software Quality Model.

5.2 Software Quality Attributes and Metrics

The software quality attributes and metrics for HydroSense focus on evaluating functionality, usability, and efficiency attributes from the ISO/IEC 9126 model. Each attribute is measured using specific formulas to determine the system effectiveness. These calculations allow developers to evaluate the system performance, pinpoint areas for improvement, and ensure that the application meets industry standards. The attributes evaluated include accuracy, attractiveness, compliance, interoperability, learnability, operability, resource utilization, and time behavior. The calculation details are found in Appendix D, where the developers applied the formulas or metrics of software quality attribute discussed in this section. This thorough evaluation ensures the system is aligned with quality benchmarks.

5.2.1 Accuracy

It measures how precisely the system sensors collect and process water quality data. It evaluates whether the measurements from the sensors (such as pH, TDS, turbidity, and temperature) meet the required precision. The method involves counting the number of data items with incorrect precision and comparing it to the total number of items requiring precise measurements. A higher accuracy score reflects fewer errors in the system calculations, ensuring reliable data for real-time analysis. Formula 1 shows the accuracy formula. It contains one subtracted from the number of data items with incorrect precision divided by the total number of data items requiring precision, then multiplied by 100 to convert it to a percentage form.

$$\boxed{AC = \left(\frac{number\ of\ data\ items\ with\ incorrect\ precision}{total\ number\ of\ data\ items\ requiring\ precision}\right) x100}$$

Formula 1. Accuracy Formula.

The accuracy of HydroSense was evaluated, focusing on the precision of the sensor data. The accuracy criterion scored 100%, as outlined in Appendix M in contaminant detection, showing that the system accurately detects water contaminants such as pH, TDS, and turbidity levels. This high score reflects the sensors reliability and the system's ability to provide precise and actionable data. Users are able to trust the system to deliver accurate measurements, which is essential for monitoring water quality and ensuring safety. The contaminant detection system performs exceptionally well, providing accurate data that supports informed decision-making.

5.2.2 Attractiveness

It evaluates the visual design and organization of the HydroSense interface, ensuring it is appealing and intuitive to users. The metric assesses how many interface elements, such as dashboards and visualizations, are customizable by the user. The attractiveness score is calculated by comparing the number of customizable interface elements to the required elements. A high score indicates a visually appealing and user-friendly interface that enhances user interaction and experience. Formula 2 shows the attractiveness formula, which contains the number of customizable interface elements divided by the total number of interface elements, then multiplied by 100 to convert it to a percentage form.

$$AT = \left(\frac{number\ of\ customized\ interface\ elements}{total\ number\ of\ interface\ elements}\right) x100$$

Formula 2. Attractiveness Formula.

The attractiveness of the HydroSense interface was evaluated across all features. The attractiveness criterion received a score of 100%, indicating that the interface visual design is appealing and engaging. Users find the system layout clean, modern, and visually pleasing, which enhances the overall user experience. This score, presented in Appendix M in the part of hydrology resources, reflects the effective design of the interface, which contributes to user satisfaction by presenting water quality data intuitively and aesthetically pleasingly.

5.2.3 ISO/IEC-9126 Compliance

It assesses the extent to which the system adheres to the specifications, standards, and requirements during development. It measures the number of correctly implemented features and compares it to the required compliance items. A high compliance score reflects that the system meets the necessary usability, functionality, and efficiency standards. By ensuring compliance guarantees that the HydroSense system operates as expected, providing reliable water quality monitoring and data management. Formula 3 shows the compliance formula. It contains the number of correctly implemented compliance items divided by the total number of required compliance items, then multiplied by 100 to convert it to a percentage form.

$$CPL = \left(\frac{number\ of\ correctly\ implemented\ compliance\ items}{total\ number\ of\ compliance\ items}\right) x100$$

Formula 3. ISO/IEC-9126 Compliance Formula.

The compliance of HydroSense features was evaluated using the ISO/IEC 9126 models, assessing usability, functionality, and efficiency standards. The hydrology resources scored 75% under the usability model, meeting most usability standards while leaving room for improvement. The contaminant detection feature scored 85.71% under the functionality model, indicating reliable and precise performance with partial adherence to functional requirements. The data visualization feature achieved a score of 100% under the efficiency model, demonstrating full compliance in resource utilization and real-time responsiveness. The water quality recommendation feature also scored 100% under the usability model, fully meeting standards for understandability, learnability, operability, and attractiveness. As highlighted in Appendix M of hydrology resources, contaminant detection, data visualization, and water quality recommendation, these scores assess the system adherence.

5.2.4 Interoperability

It evaluates the system ability to exchange and integrate data between sensors and subsystems. It assesses whether the system correctly implements data formats and communication protocols, ensuring seamless data exchange between components such as pH, TDS, and turbidity sensors. The score is determined by comparing the number of correctly implemented data formats to the required formats. A high interoperability score indicates the system functions efficiently with external systems and devices, ensuring smooth data transmission and integration. Formula 4 shows the interoperability formula. It contains the number of correctly implemented data formats divided by the required data formats, then multiplied by 100 to convert it to a percentage form.

$$\boxed{IO = \left(\frac{number\ of\ correctly\ implemented\ data\ formats}{total\ number\ of\ required\ data\ formats}\right) x100}$$

Formula 4. Interoperability Formula.

Interoperability of HydroSense was assessed across all its features, measuring the system ability to integrate and communicate with various sensors and components. The interoperability criterion scored 100%, as displayed in Appendix M in contaminant detection, indicates that the system successfully implements all required data formats and protocols, ensuring seamless data exchange between sensors. This score reflects the system ability to integrate multiple sensor types and transmit data without issues effectively.

5.2.5 Learnability

It evaluates how easily users are able to understand and use the system. It measures the completeness and clarity of help topics, documentation, and tutorials, ensuring users quickly learn how to operate the system. The score is calculated by comparing the number of fully understood help topics to the required topics. A high learnability score indicates that users potentially navigate the system with minimal training or assistance, improving overall user satisfaction. Formula 5 shows the learnability formula. It contains one subtracted from the number of incomplete help topics divided by the total number of help topics, then multiplied by 100 to convert it to a percentage form. This formula provides a straightforward way to quantify the system ease of learning and highlights areas where user support enhanced.

$$\boxed{LA = 1 - \left(\frac{number\ of\ incomplete\ help\ topics}{total\ number\ of\ help\ topics}\right) x100}$$

Formula 5. Learnability Formula.

The learnability of HydroSense hydrology resources and water quality recommendation features was evaluated using the usability model, scoring 100%, as shown in Appendix M in hydrology resources and water quality recommendation. This indicates full compliance with learnability standards, allowing users to operate these features with minimal effort or training. The hydrology resources enable users to access educational materials and water management guidelines efficiently, while the water quality recommendation feature provides intuitive guidance for interpreting water quality data.

5.2.6 Operability

Operability assesses how easily users are allowed to operate and customize system functions during regular use. It evaluates how many system functions, such as data displays or sensor settings, potentially be adjusted by the user compared to the total functions requiring customization. A high operability score suggests that users have control over key system features, improving their experience by allowing them to adjust the system to their needs. This attribute ensures that HydroSense is easy to use and is able to personalize to meet user preferences. Formula 6 shows the operability formula. It contains the number of customizable functions divided by the total number of functions requiring customization, then multiplied by 100 to convert it to a percentage form.

$$OA = \left(\frac{number\ of\ customizable\ functions}{total\ number\ of\ function\ requiring\ customization}\right) x100$$

Formula 6. Operability Formula.

The operability of HydroSense hydrology resources and water quality recommendation features was evaluated using the usability model. The hydrology resources scored 100%, indicating full compliance with operability standards and allowing users to interact with and control the features easily. The water quality recommendation feature scored 80%, meeting most operability standards and enabling effective navigation and task execution with room for improvement. These scores, as indicated in Appendix M, in hydrology resources and water quality recommendation, provide a clear assessment of the operability of both features.

5.2.7 Resource Utilization

It measures how efficiently the system uses computational resources, such as memory and processing power, during operation. It evaluates the number of input/output errors relative to the number of system calls made, such as accessing sensor data or generating reports. Few errors lead to a higher resource utilization score, indicating that the system operates efficiently without unnecessary resource consumption. This attribute ensures HydroSense runs smoothly and effectively, even under heavy workloads. Formula 7 shows the resource utilization formula, which contains the number of I/O errors divided by the number of lines of code related to system calls, then multiplied by 100 to convert it to a percentage form.

$$RU = \left(\frac{number\ of\ I/O\ errors}{number\ of\ lines\ of\ code\ related\ to\ system\ calls}\right)x100$$

Formula 7. Resource Utilization Formula.

The developers assessed the resource utilization of HydroSense, The developers assessed the resource utilization of HydroSense, particularly in the data visualization feature. The resource utilization criterion scored 75% as depicted in Appendix M in data visualization, indicates that the system meets most efficiency standards but has room for improvement. This score reflects that HydroSense manages system resources effectively under typical workloads, though optimization is needed to handle larger volumes of water quality data without potential performance degradation. Enhance resource management able to improve the system ability to operate smoothly and efficiently under all conditions.

5.2.8 Time Behavior

It evaluates the system responsiveness, particularly in time-sensitive operations such as live data streaming. It measures how many delays or lags occur during data processing and compares this to the total number of time-sensitive operations. A higher time behavior score reflects that the system responds quickly, providing users with up-to-date information on water quality without delays. This attribute ensures that HydroSense meets real-time monitoring requirements and delivers accurate, timely data to users. Formula 8 shows the time behavior formula, which contains the time delays divided by the total number of data streams, then multiplied by 100 to convert it to a percentage form.

$$TB = \left(\frac{number\ of\ time\ delays}{total\ number\ of\ data\ streams}\right) x100$$

Formula 8. Time Behavior Formula.

The time behavior of HydroSense was evaluated across all features, with a particular focus on real-time data visualization. The time behavior criterion scored 100% as provided in Appendix M in data visualization, shows that the system responds instantly to user inputs and provides real-time data updates without delays. This high score reflects the system efficiency in processing and displaying data, ensuring that users receive up-to-date information promptly. The fast response times ensure HydroSense is highly effective in real-time water quality monitoring.

5.2.9 Understandability

It evaluates how well users comprehend the purpose and functions of HydroSense. It measures how easily users are able to interpret the system user interface and features, ensuring that they use the system without confusion. The score is calculated by comparing the number of fully understood interface functions to the total number of required interface functions. A high understandability score indicates that users easily navigate the system and interact with its features, improving the user experience. Formula 9 shows the understandability formula, which contains the number of UI functions whose purpose is understood by the user divided by the total number of user interface functions, then multiplied by 100 to convert it to a percentage form.

$$UA = \left(\frac{number\ of\ UI\ functions\ whose\ purpose\ is\ understood\ by\ user}{total\ number\ of\ user\ interfaces\ functions}\right) x100$$

Formula 9. Understandability Formula.

The understandability of HydroSense hydrology resources and water quality recommendation features was evaluated using the usability model, with both scoring 100%, as provided in Appendix N. These scores indicate full compliance with understandability standards, demonstrating that users easily comprehend both features purpose and functionality. The hydrology resources provide clear and intuitive information, while the water quality recommendation feature offers concise and easily interpretable guidance. These evaluations confirm that both features meet the defined usability criteria for understandability.

5.3 Hardware Quality Attributes and Metrics

The hardware quality attributes and metrics for HydroSense focus on evaluating key aspects of system performance, reliability, and resilience using the ISO/IEC 30141 model. Each attribute is measured using specific formulas to assess the effectiveness of the hardware components, including sensors and communication modules. These calculations in Appendix N help developers identify areas of improvement and ensure that the system adheres to IoT industry standards. The evaluated attributes include availability, confidentiality, integrity, reliability, resilience, safety, heterogeneity, modularity, network connectivity, compliance, data characteristics, and real-time capability. As discussed in this section, detailed calculations and evaluation metrics are provided to ensure that the hardware components meet the necessary performance and operational standards. This comprehensive evaluation supports developing a robust, high-performance system that meets current and future IoT needs.

5.3.1 Availability

The availability criterion in this internal quality measurement relates to the operational uptime of the hardware. The procedure counts the number of operational instances when the sensors or devices were online and compares it to the total operational time. The availability attribute was measured to determine whether the hardware elements, including the pH, TDS, turbidity, and temperature sensors, were functioning without interruptions. As indicated in Formula 10, one is subtracted from the number of unplanned hardware downtimes, divided by the total number of operational instances, and then multiplied by 100 to get the percentage.

$$\boxed{A = \left(1 - \frac{number\ of\ unplanned\ hardware\ downtimes}{total\ number\ of\ operational\ instances}\right) x100}$$

Formula 10. Availability Formula.

The developers evaluated the HydroSense hardwares availability based on its sensors' operational uptime. The availability criterion received a score of 100.00%, as referenced in Appendix N in IoT system trustworthiness characteristics, indicating that the sensors and devices remained operational without any unplanned downtimes. This signifies that the system consistently performed its functions, ensuring that data collection and transmission were uninterrupted. This high availability reinforced user trust in the reliability of the system. It also demonstrated HydroSense suitability for continuous water quality monitoring.

5.3.2 Confidentiality

It measures the security of transmitted data to ensure it is encrypted and protected. The procedure counts the number of secure transmissions from the sensors to the server and compares it to the total number of transmissions made. The confidentiality attribute was measured to ensure sensor data security, such as pH, TDS, turbidity, and temperature readings. As shown in Formula 11, the number of secure transmissions is divided by the total number of data transmissions and then multiplied by 100 to convert it to a percentage. This metric provides a clear indicator of the system reliability in safeguarding sensitive data against potential breaches or unauthorized access.

$$\boxed{CY = \frac{number\ of\ secure\ transmissions}{total\ number\ of\ data\ transmissions}}$$

Formula 11. Confidentiality Formula.

The confidentiality of HydroSense was assessed by evaluating the security of data transmissions from the sensors. This criterion received a score of 83.33%, as highlighted in Appendix N in IoT system trustworthiness characteristics, indicating that most data transmissions were securely encrypted, with some areas requiring improvement. The result shows that the system-maintained data privacy for most transmissions, though there is room to enhance security measures. To address these gaps, ensured that all sensitive information was transmitted securely and without breaches.

5.3.3 Integrity

It refers to the accuracy of the data transmitted from the sensors to the system, ensuring no data is corrupted or altered. The procedure compares the number of data packets transmitted correctly to the total number of packets sent by the sensors. This criterion was measured for pH, TDS, turbidity, and temperature data integrity. As indicated in Formula 12, the number of correctly transmitted data packets is divided by the total number of transmitted packets, then multiplied by 100 to obtain the percentage.

$$\boxed{I = \frac{number\ of\ correctly\ transmitted\ data\ packets}{total\ number\ of\ transmitted\ packets} x100}$$

Formula 12. Integrity Formula.

The integrity criterion was evaluated to determine the accuracy and reliability of the data transmitted from HydroSense sensors to the system. This assessment ensures that the data collected by sensors, such as pH, turbidity, and temperature readings, remains accurate and unaltered during transmission. The integrity criterion received a score of 100.00%, as shown in Appendix N in IoT system trustworthiness characteristics, indicating that no data corruption, loss, or alteration occurred throughout the transmission process. This result highlights the systems robust design and adherence to integrity standards, ensuring that the data remains precise and reliable for analysis and decision-making. It is crucial to maintain this level of integrity to provide users with dependable water quality monitoring, as any errors in data transmission compromise the system effectiveness and user trust.

5.3.4 Reliability Sensor

The reliability criterion relates to the consistency of sensor data collection and processing over time. It involves comparing the number of consistent readings to the total readings obtained. This ensures that pH, TDS, turbidity, and temperature sensors provide consistent data across different conditions. As described in Formula 13, the number of consistent sensor readings is divided by the total number of sensor readings and multiplied by 100 to generate the reliability percentage.

$$RY = \frac{number\ of\ consistent\ sensor\ readings}{total\ number\ of\ sensor\ readings} x100$$

Formula 13. Reliability Sensor Formula.

The developers assessed the reliability of the HydroSense system by evaluating the consistency of sensor readings under varying conditions. The reliability score was 100.00%, as provided in Appendix N in IoT system trustworthiness characteristics, indicating that all sensors consistently produced reliable data. This result signifies that HydroSense hardware components operated consistently over time without performance degradation.

5.3.5 Resilience

It measures the system ability to recover from disruptions or failures, such as network or power issues. It compares the number of successful recoveries to the total number of disruptions. This criterion was applied to ensure the recovery capability of HydroSense in situations where pH, TDS, turbidity, or temperature sensors face temporary failures. As indicated in Formula 14, the number of successful recoveries from system failures is divided by the total number of failures, then multiplied by 100 to convert it into a percentage. A high recovery rate demonstrates the systems resilience and ability to maintain reliable operation under adverse conditions.

$$RE = \frac{number\ of\ successful\ recoveries\ from\ system\ failures}{total\ number\ of\ failures} x100$$

Formula 14. Resilience Formula.

HydroSense resilience was evaluated by measuring its ability to recover from network outages or power failures. The resilience criterion received a score of 100.00%, as exhibited in Appendix N in IoT system trustworthiness characteristics. This indicates the system successfully recovered from all disruptions without losing data or functionality. HydroSense is highly resilient, ensuring continuous operations even in adverse conditions.

5.3.6 Safety

The safety criterion refers to the secure and reliable operation of the hardware under safe conditions. It compares the number of safe operational instances to the total operational instances. This criterion is important to ensure that all sensors operate safely without causing any hazards. As stated in Formula 15, the number of safe operational instances is divided by the total number of operational instances, then multiplied by 100 to generate the safety percentage.

$$S = \frac{number\ of\ safe\ operational\ instances}{total\ number\ of\ operational\ instances} x100$$

Formula 15. Safety Formula.

The developers evaluated the safety of HydroSense by ensuring that all sensors and devices operated within secure and safe conditions. The safety criterion received a score of 100.00%, as indicated in Appendix N in IoT system trustworthiness characteristics, meaning that all operational protocols were followed, and no safety issues were detected. This result signifies that HydroSense hardware is safe to operate in real-world environments without risk to users or equipment. This achievement highlights the system readiness for deployment in diverse environmental conditions.

5.3.7 Heterogeneity

It refers to the capability of the system to integrate and work with different types of sensors or devices. It compares the number of successfully integrated sensors to the total types of sensors in the system. This criterion evaluates the successful integration of pH, TDS, turbidity, and temperature sensors. This ensures the adaptability of the system to various sensors. As indicated in Formula 16, the number of successfully integrated sensor types is divided by the total number of sensor types and multiplied by 100 to obtain the percentage.

$$H = \frac{number\ of\ successfully\ integrated\ sensor\ types}{total\ number\ of\ sensor\ types} x100$$

Formula 16. Heterogeneity Formula.

Heterogeneity was assessed by evaluating HydroSense ability to integrate various types of sensors. The system received a score of 100.00%, as calculated in Appendix N in IoT system architecture characteristics, indicating that it successfully integrated all sensor types, including pH, TDS, turbidity, and temperature sensors. This result signifies that HydroSense architecture is flexible and supports various sensor types without compatibility issues.

5.3.8 Modularity

It measures the ease with which components of the system able be replaced or upgraded. It compares the number of modular components that manage to replace the total number of components. This criterion evaluates whether sensors are able to be replaced or added in a modular manner. As described in Formula 17, the number of replaceable modular components is divided by the total number of modular components and multiplied by 100 to calculate the modularity score. A high modularity score indicates a flexible and future-proof system design that simplifies maintenance and accommodates technological advancements.

$$M = \frac{number\ of\ replaceable\ modular\ compornents}{total\ number\ of\ modular\ components} x100$$

Formula 17. Modularity Formula.

The modularity of HydroSense was assessed by evaluating the ease with which its components potentially be replaced or upgraded. The modularity criterion received a score of 75.00%, as outlined in Appendix N in IoT system architecture characteristics, reflecting that while the system supports modular replacement, there is room for improvement. This result signifies that the system is somewhat modular, allowing for partial upgrades or replacements of sensors, but improvements in this area enhance the system flexibility.

5.3.9 Network Connectivity

It measures the stability and reliability of the sensor connections to the network. It compares the number of successful network connections to the total connection attempts. This criterion ensures the connectivity of pH, TDS, turbidity, and temperature sensors to the server. As shown in Formula 18, the number of successful network connections is divided by the total number of connection attempts and multiplied by 100 to compute the percentage.

$$\boxed{NC = \frac{number\ of\ successful\ network\ connections}{total\ number\ of\ connection\ attempts} x100}$$

Formula 18. Network Connectivity Formula.

The developers assessed HydroSense network connectivity by evaluating the stability and reliability of its connections to the network. The network connectivity criterion received a score of 80%, as referenced in Appendix N in IoT system architecture characteristics, indicating that most sensor connections were stable and reliable, though some areas require improvement. This score reflects partial compliance with connectivity standards, highlighting occasional issues that are able to affect seamless data transmission. Enhance network stability, improve the overall system performance, and ensure consistent communication between sensors and the system. Addressing these connectivity issues strengthen the system overall reliability and data accuracy in real-world applications.

5.3.10 ISO/IEC-30141 Compliance

It refers to the adherence of the hardware components to system performance standards. It compares the number of components that meet performance requirements to the total number of components in the system. This criterion ensures that all sensors perform within the required specifications. As stated in Formula 19, the number of compliances with performance and optimal requirements is divided by the total number of hardware elements, then multiplied by 100 to calculate the compliance score.

$$CE = \frac{n\ of\ compliances\ with\ performance\ and\ optimal\ requirements}{total\ number\ of\ hardware\ elements} x100$$

Formula 19. ISO/IEC-30141 Compliance Formula.

Compliance was evaluated by assessing whether HydroSense hardware components met the required system performance standards. The compliance criterion received a score of 100.00%, as presented in Appendix N in IoT system functional characteristics, meaning that all components operated within the specified performance requirements. This result signifies that HydroSense hardware meets all the necessary functional standards, ensuring reliable performance.

5.3.11 Data Characteristics

It relates to the ability of the system to handle different data types and ensure accuracy. It compares the number of correctly processed data types to the total required data types. This criterion ensures that pH, TDS, turbidity, and temperature data are handled accurately. As shown in Formula 20, the number of data types processed correctly is divided by the total required data types and multiplied by 100 to get the percentage.

$$DC = \frac{number\ of\ data\ types\ processed\ correctly}{total\ required\ data\ types} x100$$

Formula 20. Data Characteristics Formula.

Data characteristics were assessed by evaluating HydroSense ability to process different types of data accurately. The data characteristics criterion received a score of 100.00% referenced in Appendix N in IoT system functional characteristics, reflecting that all sensor data types were correctly handled and processed. This result shows that HydroSense accurately collects and processes data, ensuring its integrity. It demonstrates robustness and reliability, making it a dependable tool for water quality management.

5.3.12 Real-Time Capability

It measures how well the system delivers real-time updates for sensor data. This criterion is essential for pH, TDS, turbidity, and temperature sensors, ensuring they provide real-time data without delays. As indicated in Formula 21, the number of real-time updates provided is divided by the total number of required updates and multiplied by 100 to obtain the percentage.

$$RC = \frac{number\ of\ real - time\ updates\ provided}{total\ number\ of\ required\ updates} x100$$

Formula 21. Real-Time Capability Formula.

Real-time capability was evaluated based on HydroSense ability to provide real-time updates from its sensors. The real-time capability criterion received a score of 85.71% as presented in Appendix N in IoT system functional characteristics. This indicates that the system usually delivers real-time data, though some delays are possible. This score reflects partial compliance with real-time standards, suggesting the need for optimization to ensure consistent, immediate updates. Removing these delays enhances HydroSense suitability for time-sensitive applications.

5.4 Safety and Security Requirements

HydroSense is a water quality monitoring system designed for use in various environments and settings such as in a residential setting. The system ensures the safety and security of data by utilizing encryption for all sensor data transmissions, safeguarding sensitive information such as pH, TDS, turbidity, and temperature readings from unauthorized access. The hardware components of HydroSense are designed to operate safely under various conditions, adhering to strict safety standards to prevent electrical malfunctions or data corruption. Additionally, the system built-in security measures ensure that sensor readings remain accurate and intact throughout data collection and transmission. Users are provided with clear guidelines on operating the system safely, and all data is processed in real time while maintaining high levels of integrity and confidentiality. This comprehensive approach ensures that HydroSense remains a reliable and secure tool for monitoring water quality. It allows users to make informed decisions based on trustworthy data and enhances the system value in diverse applications.

5.5 Testing Requirements

Testing is vital in HydroSense development to ensure all components function as intended and meet operational standards. Through testing, developers identified issues, refined functionalities, and optimized the system overall performance. Testing phases included unit testing of individual sensors, integration testing to ensure seamless operation among components, and system testing to evaluate the system real-world performance. These steps helped improve the reliability and functionality of HydroSense, ensuring it delivered accurate data. The following sections detail the specific testing methodologies used.

5.5.1 Unit Testing

Unit testing for HydroSense evaluating individual components of the system to ensure they functioned correctly in isolation. Each module, including the

TDS, pH, turbidity, temperature sensors, and web application data visualization and logging features, was tested independently. The team developed test cases for specific functionalities, such as accurate data readings from sensors, responsiveness of the OLED display, and proper storage of data in CSV format. Any bugs or anomalies identified during these tests were resolved before the integration phase. The unit testing process helped the team verify that each component met its design specifications and contributed effectively to the overall system.

5.5.2 Integration Testing

The integration testing process focused on verifying the compatibility between the Arduino-based hardware, including sensors, and the web application for real-time data transmission and visualization. To assess data accuracy and system resilience, the developers employed test cases that simulated real-world scenarios, such as fluctuating water quality parameters and network interruptions. Any detected inconsistencies between the modules were documented and resolved to ensure a robust and reliable system. The team emphasized collaboration during this phase, involving hardware and software specialists to troubleshoot and refine the integration process. Overall, this approach validated all components effective interaction, ensuring HydroSense performed as designed.

5.5.3 System Validation

It is focused on verifying HydroSense overall functionality and performance in a real-world environment. Developers assessed the system resilience to network interruptions and power failures while ensuring continuous sensor operation. Testing assessed the systems accuracy and speed in delivering real-time water quality data. It was deployed under various conditions to verify reliability and data integrity, with stress tests ensuring robust performance under peak loads. Additionally, feedback from test users was incorporated to identify and address usability challenges, further refining the system. This final testing phase ensured that HydroSense met the required performance standards for water quality monitoring. The thorough testing process guarantees HydroSense operates effectively in diverse conditions and meets user expectations for reliability and performance.

5.5.4 Acceptance Testing

During this phase, the application approached completion, with the defects mentioned in the survey resolved. A total of thirty individuals participated in testing the application. The six IT students, twenty-one non-IT students, and one faculty member are from UNO-Recoletos and two other school visitors. Users interacted or watched the application demo before completing surveys, providing feedback to guide enhancements. Confidentiality of personal information was strictly maintained. The application was tested face-to-face, with participants completing a detailed questionnaire via Google Forms. The survey also gathered qualitative feedback to capture participants specific suggestions for improvements. This feedback was instrumental in refining the user interface and addressing minor issues before deployment. Furthermore, participants unanimously highlighted the systems intuitive design and ease of use, contributing to its high overall satisfaction ratings. This evaluation measured accuracy, simplicity, security, and overall user satisfaction using a scale of one to five, with five being the highest. The mean score was computed, and its description was identified using Table 20.

Mean Score	Interpretation
4.21 – 5.00	Very Good
3.41 – 4.20	Good
2.61 – 3.40	Average
1.81 – 2.60	Poor
1.00 – 1.80	Very Poor

Table 20. Survey Result Interpretation.

Table 21 summarizes the evaluation of the application based on various criteria, mean scores, and their interpretations, with 30 participants providing ratings. The criteria listed have a mean score ranging from 4.30 to 4.67. The developers then identified the top three mean scores and the lowest three scores. This analysis provided valuable insights into the applications strengths and areas for potential enhancement, ensuring a balanced approach to future updates. These findings guide the development of targeted improvements in upcoming versions. Participants highlighted specific features that exceeded expectations, such as the user-friendly interface and accurate data visualization. Conversely, suggestions were made to refine areas like response time and advanced customization options for enhanced usability. This feedback is instrumental in aligning the application with user expectations and industry benchmarks. It also fosters continuous improvement, ensuring the system remains reliable and user focused.

Criteria	Mean Score	Interpretation
Accuracy	4.60	Very Good
Auditability	4.60	Very Good
Communication Commonality	4.67	Very Good
Completeness	4.60	Very Good
Conciseness	4.43	Very Good
Consistency and Understandability	4.51	Very Good
Controllability	4.49	Very Good
Data Commonality	4.63	Very Good
Decomposability	4.43	Very Good
Error Tolerance	4.40	Very Good
Execution Efficiency	4.53	Very Good
Expandability	4.53	Very Good
Generality	4.46	Very Good
Hardware Independence	4.37	Very Good
Instrumentation	4.53	Very Good
Modularity	4.33	Very Good
Observability	4.34	Very Good
Operability	4.42	Very Good
Security	4.63	Very Good
Self-Documentation	4.30	Very Good
Functional Simplicity	4.50	Very Good
Structural Simplicity	4.40	Very Good
Code Simplicity	4.50	Very Good
Software System Independence	4.50	Very Good
Traceability	4.50	Very Good
Training	4.60	Very Good

Table 21. Summary of Survey Results.

The top highest criteria for HydroSense are communication commonality (4.67), execution efficiency (4.53), and expandability (4.53). Communication commonality reflects standard interfaces and protocols, ensuring seamless communication between components and a user-friendly interface. Execution efficiency highlights the system runtime performance, showing that HydroSense processes data swiftly and reliably during real-time water quality monitoring.

Expandability demonstrates the system ability to extend its architectural, data, or procedural design, allowing for future enhancements, such as additional sensors or features. These high scores underscore HydroSense robust design and adaptability to meet diverse user needs. This solid performance in key areas reinforces HydroSense as an effective and scalable solution for water quality management. It positions the system to easily accommodate future technological advancements and evolving user requirements.

Conversely, the criteria with relatively lower scores are self-documentation (4.30), modularity (4.33), and observability (4.34). self-documentation pertains to the degree to which the source code provides meaningful comments and explanations, which improves for easier maintenance and development. Modularity reflects the independence of program components, where some modules are likely to have dependencies that are optimized. Observability refers to the ability to monitor system states and outputs, where improvements help users better trace and identify issues during operation. Despite these areas for enhancement, all criteria received ratings categorized as very good, ranging from 4.30 to 4.67, showcasing HydroSense overall high quality and effectiveness in delivering its intended functionality.

The project performance requirements for HydroSense have been thoroughly outlined in this chapter. Key quality attributes for both hardware and software were defined, with metrics provided to evaluate their performance. Testing methodologies, including unit, integration, system, and acceptance testing, were detailed, ensuring that

HydroSense met operational and safety standards. Results from the evaluations, which scored all criteria as "Very Good," highlight the system reliability, usability, and efficiency, while identifying areas like self-documentation and modularity for potential improvement. The positive results from the testing phase validate the system ability to perform accurately and consistently in real-world scenarios. Feedback collected from testing was used to refine the user interface, making it more intuitive and accessible. The modular design was recognized as a strength, offering flexibility for future upgrades. Areas for improvement, such as enhancing the self-documentation feature, were noted for further development. Overall, the comprehensive testing process ensures HydroSense is a reliable and high-performing tool for water quality monitoring.