

Application of an Expert System for Quality Control Management in Food Industry: A Case Study of Water Processing Industry in UNIOSUN

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Abstract This study developed an expert system for quality control management in the water processing industry. The system integrates advanced algorithms and industry expertise to provide real-time recommendations for water treatment and quality control. A comprehensive knowledge base was developed through a review of industry guidelines, expert opinions and scientific literature. The expert system features a user-friendly interface and accurately evaluates water quality, flagging samples outside acceptable ranges. A case study involving the analysis of 10 water samples demonstrated the system's effectiveness in ensuring water quality within safe limits for human consumption. The expert system has the potential to enhance quality control management in the water processing industry, ensuring the delivery of high-quality products and safeguarding consumer health.

Keywords: Expert system, quality control, safe water, water processing

I. Introduction

Quality Control Management (QCM), championed by diligent management, proactive leadership, and a well-organized structure, provides a systematic approach to enhancing quality and overall organizational performance. This coordinated system encompasses quality planning, control, assurance and improvement, ensuring specified standards are met and customer needs are fulfilled. By integrating these elements, QCM enables organizations to adopt a structured framework for achieving continuous customer satisfaction and retention [1].

QCM emphasizes the holistic approach to quality which goes beyond making a product meets specifications but intertwined with productivity, product design and a host of other related issues. Quality control management pays attention to the beginning, middle and end of the production process [2]. In today's competitive market, quality has become a crucial

factor in consumer decision-making, particularly when it comes to food products, where the risks associated with sub-standard quality are high [3]. Without effective quality control measures, consumers may be exposed to potentially hazardous products, compromising their health and well-being. Therefore, effective QCM systems are essential for food industries to ensure the delivery of high-quality products, safeguard consumer health, and maintain a competitive edge. Lihua [4] highlights the importance of food physical and chemical testing for ensuring food quality and safety especially when food safety issues posing health risks to consumers. The study provides control interference factors, such as environmental and human factors, reagent purity, instrument accuracy, and experimental method selection, to analyze quality control measures in food physical and chemical testing, discuss strategies to minimize interference factors, provide recommendations for improving food testing accuracy.

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The water processing industry which is a growing food industry, particularly in developing nations, originated as a response to the scarcity of safe drinking water, needs to maintain a high quality standard to achieve its targeted objective of ensuring public safety which is one of the many reasons for bottled and sachet water consumption [4, 5]. The water processing industry's quality control management has become increasingly challenging due to mass-production that involves in the making of the products. While mass-production, enabled by division of labour and machinery, has boosted productivity, it has also introduced numerous variables affecting quality control management [6]. As a result, manufacturers have had to adopt more sophisticated quality control measures beyond standardized measurements.

There are various steps, methodologies and tools that are utilized to maintain high-quality standards and facilitate continuous improvement within an organization [7]. Among these, two prominent methods lean and six sigma have been amalgamated into a unified approach [8]. Lean production, also known as lean manufacturing or lean management, serves as a managerial framework aimed at organizational enhancement, emphasizing the elimination of waste and reduction of costs [9]. Alternatively, Six Sigma, originating during Japan's quality evolution and at Motorola, aims to uphold final product quality by emphasizing the attainment of substantially higher levels of conformance [10]. Six Sigma is a data-driven methodology that employs statistical analysis to identify root causes of problems and assess process performance, utilizing its own unit of measurement known as the Sigma unit [7].

In small-scale food industries, the accuracy of quality evaluations is often hindered by the

absence of professional quality control personnel and non-adherence to analytical protocols. This can result in inaccurate and biased assessments of finished product quality [11]. To improve objectivity in food quality control, the integration of advanced intelligent technologies into the production process is essential. This can be achieved by developing automated control and management systems that utilize modern technologies, including artificial neural networks (ANN) and computer vision systems, within integrated expert systems (ES) for real-time monitoring and forecasting of product quality indicators.

The application of ES in the food industry has been increasing for years due to various reasons such as food sorting, classification and prediction of the parameters, quality control, and food safety. ES fuzzy logic, ANN, adaptive neuro-fuzzy inference system (ANFIS) and machine learning (ML) are among the popular techniques that have been utilized in the food industries to automate the management of quality control [3, 12, 13].

ES represents a subset of applied artificial intelligence (AI) and emerged from the AI community during the mid-1960s. The fundamental concept of ES revolves around the transfer of expertise, or task-specific knowledge, from humans to computers. This knowledge is then stored within the computer system, allowing users to access it for specific advice as required. The computer is capable of making inferences and reaching conclusions based on the stored knowledge. Similar to a human consultant, the ES provides advice and can explain the logic behind its recommendations if necessary [3]. ES offers powerful and adaptable methods for resolving a variety of problems that may not be effectively addressed through

conventional methods. As a result, their utilization is expanding across various sectors of our social and technological landscape. Their applications are proving to be indispensable in facilitating decision support and problem-solving processes [14]. These systems store factual information and expertise in a knowledge base, integrating them with an inference or rules engine. The inference engine utilizes a set of rules applied to the knowledge base to address problems provided in the program. It heavily relies on a well-maintained knowledge base and continuously updates the information in the knowledge base, which non-experts can then utilize for complex problem-solving. However, for particularly intricate problems, human expertise may still be necessary.

ES have been recognized as a valuable technological tool in aiding organizations in identifying project challenges and developing effective solutions. A study by Chhajer [15] examined the impact of ES on human decision-making capabilities, revealing a positive influence on organizational operational efficiency, human decision-making abilities, and business growth.

Further research on the methodologies and applications of AI and ES has been conducted by Yousef et al [16], Tan et al [17] and Ali and Hacinnahmud [18]. These studies highlight the significance of AI and ES in enhancing human activities, but also acknowledge the challenges associated with creating and deploying ES, including knowledge gathering issues, maintenance difficulties, and limited system lifespan. To address these challenges, a new methodology has been proposed, incorporating suggestions to extend the lifespan of knowledge-based ES. This methodology involves six stages: identification, conceptualization, formation,

realization, tuning and testing, and test operation and application.

The literature also emphasizes the breadth of AI technology, encompassing various systems such as rule-based ES, fuzzy logic, ANN, and genetic algorithms. Key aspects of ES development include knowledge acquisition and representation, prototyping and iterative design, testing and validation and involvement of experts and end-users. These findings provide a foundation for further research on the development and application of ES and AI in various fields.

The development of ES has been recognized as a crucial step in improving product quality assessment in the food industry. According to Blagoveshchenskiy et al [11], existing methods of quality assessment are imperfect due to the lack of professional quality control personnel and non-compliance with analytical protocols. To address this issue, Blagoveshchenskiy et al [11] developed a database for ES that integrates disparate data into a single system, enabling specialists to make changes to existing standard calculation methods and provide recommendations for monitoring product properties.

Similarly, Blagoveshchenskiy et al [11] noted that current product quality assessment methods are imperfect and rely heavily on laboratory testing within enterprises. To improve product quality assessment, the study proposed the development of ES that can monitor and forecast product quality indicators using intelligent technologies. The proposed ES includes the creation of a comprehensive database, development of a conceptual model of the domain database, and design of the database architecture.

In addition to these studies, Paladini [19] developed a decision supporting expert system (DSES) for quality inspection. The DSES aims to aid decision-making for quality inspection by guiding users through preliminary activities, determining the need for inspection, and selecting the appropriate inspection type. The system supports informed decision-making in quality inspection, enhancing efficiency and effectiveness.

Overall, these studies demonstrated the potential of ES in improving product quality assessment and control in industry. The development of comprehensive databases, conceptual models, and database architectures are critical components of ES. Furthermore, the integration of intelligent technologies and decision-support systems can enhance the efficiency and effectiveness of quality inspection processes.

The application of AI in food industries and water bottling plants has gained significant attention in recent years. Comprehensive reviews AI applications in food industries can be found in Filter et al [12], Addanki et al [13] and Peris [20]. These studies highlight the importance of AI, ML, and ES in enhancing food quality, safety, and production, emphasizing the need for collaborative efforts and community-driven approaches to advance these technologies.

Several studies have examined the application of AI and ES in specific contexts. For instance, Ihunwo and Kinigoma [21] applied statistical process control (SPC) to improve quality in a water bottling plant, recommending the integration of AI with SPC to enhance quality control. Meanwhile, Mavani et al [3] provided a comprehensive review of the transformation of the food industry through the integration of AI, highlighting its applications in food quality

assessment, control systems, classification, and predictive analytics.

Other studies have explored the development of AI-powered systems to enhance customer satisfaction and streamline processes. For example, Arpita et al [22] developed an online food ordering system using a web-based application, which simplifies the ordering process, reduces manual work, and enhances customer satisfaction.

Overall, these studies demonstrate the potential of AI and ES to transform the food industry and water bottling plants, highlighting the need for further research and development to fully leverage these technologies.

II. Expert System Structure

The Expert system was structured to provide real-time recommendation for water treatment and quality control, leveraging advanced algorithms and industry expertise. The knowledge base was developed through a comprehensive review of; industry guidelines and regulations of national agency for food and drug administration and control (NAFDAC), expert opinions and interviews with the industry professionals in UNIOSUN Integrated Venture, scientific literature and research papers related to water quality control and using existing quality control protocols and procedures.

Figure 1 shows the structure of the ES developed for the quality control management of water processing industry.

The knowledge base was represented using a hybrid approach, combining: object-oriented programming (OOP) concepts in JavaScript, neural networks and machine learning algorithms (TensorFlow.js) and rule-based

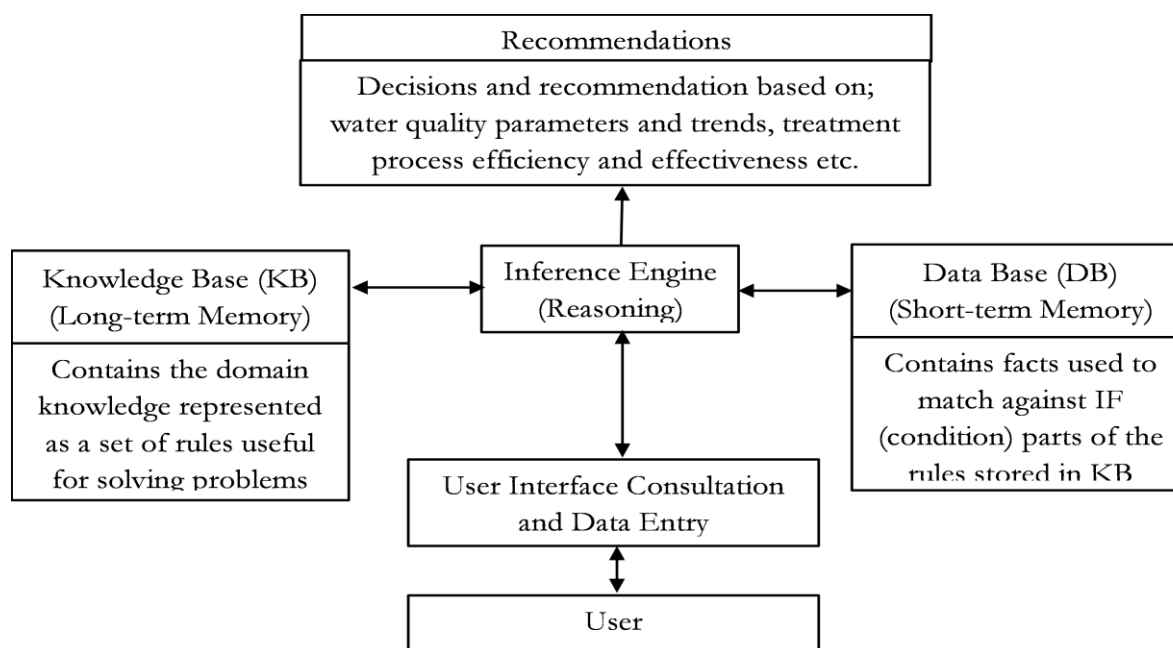


Figure 1: Structure of the Expert System [23]

systems and decision trees. This representation enables efficient reasoning, inference, and decision-making. This is the brain of the ES containing the rules and information it uses to make decisions. It maps specific defects to corresponding input values, allowing the system to provide accurate notifications. Semantic nets, frames and (IF-THEN) rules are employed for representing the knowledge.

The inference engine was developed using Node.js, leveraging the knowledge representation to; process input data from various sources (sensors, databases, and user inputs), apply reasoning and inference techniques to generate recommendations and provide real-time output for water treatment and quality control.

The User interface is the part of the ES where; users input values for parameters and users submit their input values for evaluation by the ES. This interface also include the Administration interface which is the brain

“behind-the scenes” where authorized administrators can; update the ES’s knowledge base (the rules and information it uses to make decisions), change the acceptable ranges for parameters, add new parameters or remove old ones and modify the notification messages that users receive.

The Database prompt the ES to check the user’s input values against the acceptable ranges set by the administrators. If any value is outside the acceptable range, the system triggers a notification alert as recommendations.

The ES as integrated with; sensors systems for real-time water quality monitoring, database systems for historical data analysis and trend detection and using existing protocols. The ES generates decisions and recommendations based on; water quality parameters and trends, treatment process efficiency and effectiveness, chemical usage and optimization, and quality control and assurance protocols.

III. Design and Development of Expert System

This study adopts the following steps in developing the ES; knowledge acquisition, knowledge representation, system development, system validation.

A. Knowledge Acquisition

In this study, knowledge acquisition was facilitated through expert opinions, experiences and data from food and drug regulatory body [24]. The data used was collected from the UNIOSUN Water Factory situated at Osun State University, Main Campus, Oke-Baale, Osogbo, Osun State, Nigeria, which happens to be a part of the UNIOSUN Integrated Ventures

Limited. The water factory produces sachet and bottle water and distribute its products within and outside Osogbo Metropolis. The factory's quality control measures focus on physicochemical and microbiological characteristics, including pH, conductivity, temperature, total dissolved solids (TDS), and faecal coliform, among others.

The available data from the factory includes pH, TDS, conductivity, total hardness (TH) and magnesium hardness (MH). Table 1 presents the standard ranges for these parameters, as specified by NAFDAC. These parameters serve as indicators of water quality and are essential for ensuring the safety and potability of the water produced by the factory.

Table 1: NAFDAC Standards for pH, TDS, C, TH and MH

S/N	Parameters	NAFDAC Standard
1	pH	6.5 – 8.5
2	Total Dissolve Solids-TDS (mg/l)	0 – 500
3	Conductivity- C ($\mu\text{s}/\text{cm}$)	0 – 1000
4	Total Hardness-TH (mg/l)	0 – 100
5	Magnesium Hardness-MH (mg/l)	0 – 30

B. Knowledge Representation

Extracting knowledge from domain experts is a crucial step in developing ES. Typically, a knowledge engineer, trained in knowledge extraction, works closely with domain experts to gather and formalize their knowledge. This collaborative approach ensures that the ES's knowledge base accurately reflects the experts' experience and expertise.

The knowledge base is the core component of an ES containing the domain-specific knowledge necessary for problem-solving. This knowledge is represented as a set of rules, each with a conditional (IF) and action (THEN) structure. These rules capture relationships, recommendations, directives, strategies, and heuristics relevant to the domain. When the conditions specified in a rule are met, the rule "fires," triggering the execution of the

corresponding action. This rule-based system enables the ES to reason, draw conclusions and provide informed decisions.

C. Expert System Development

The ES was developed to be user-friendly and accessible. It was developed using JavaScript and features two interfaces; administrative interface:

for authorized personnel to update parameters ranges, manage user access and customize notification messages, then the user or main interface: for end-users to input water quality data, receive alerts and recommendations, and view results in a user-friendly format. These two interfaces are shown in Figure 2 and Figure 3, respectively

The image displays a web interface for an expert system. At the top, there is a 'Login to Admin' section with two input fields: the first contains 'hey@gmail.com' and the second contains 'hey@gmail'. Below these fields is a black 'Log in' button. Below the login section is the 'ADMIN PAGE' header, followed by a black 'Logout now' button. The main content area is divided into five sections for setting ranges: 'Set PH range', 'Set TDS range', 'Set Conductivity range', 'Set Total Hardness range', and 'Set Magnesium Hardness range'. Each section has two input fields labeled 'min acceptable value' and 'max acceptable value'. At the bottom of the form is a large black 'Submit' button.

Figure 2: Administrative Interface

EXPERT SYSTEM FOR QUALITY CONTROL
Enter your readings below to test the quality and composition of your specimen

PH value
Enter the PH value

Total Dissolve Solids (TDS)
Enter the TDS value

Conductivity
Enter the conductivity value

Total Hardness
Enter the total hardness value

Magnesium Hardness
Enter the magnesium hardness value

Submit

Figure 3: User or Main Interface

D. System Validation

Following its completion, the ES module underwent verification testing to ensure its accuracy. Furthermore, a domain expert, the officer in-charge of the quality control of the factory, conducted an extensive validation of the system using available data in the factory. This rigorous evaluation aimed to confirm that the system generated correct results and satisfied user requirements. The following validation involves the following basic steps; login, system initialization, data input, recommendation output, decision-making and system update.

IV. Results and Discussion

The ES features a user-friendly interface that enables users to input parameters manually, facilitating seamless interaction. To assess the

quality status of a water sample, users enter relevant data through the main/user interface. The system then generates recommendations based on standard parameters previously input through the administrative interface.

A comprehensive case study was conducted, involving the analysis of 10 water samples collected over several days. The input data for these samples with the corresponding results generated by the ES is presented in Table 2. Additionally, Figures 4 and 5 offer a visual representation of the system's output for samples I and V, effectively illustrating its recommendation capabilities.

The ES accurately evaluated water quality, flagging samples outside acceptable ranges as "not up to standard." Specifically; pH values below 6.5 or above 8.5 were rejected, Total

Table 2: Data for 10 Water Samples and ES Outputs

Sample	Data					Expert System's Output	
	pH	TDS (mg/l)	Conductivity (μ s/cm)	Total Hardness (mg/l)	Magnesium Hardness (mg/l)	Result	Remark
I	6.5	66	15	30	30	Accepted	Data meets the expected quality standards.
II	7.2	106	17	30	28	Accepted	Data meets the expected quality standards.
III	7.0	125	23	35	29	Accepted	Data meets the expected quality standards.
IV	7.1	200	15	36	32	Rejected	Hardness are out of range.
V	12	540	14	29	40	Rejected	pH, TDS and Magnesium Hardness are out of range.
VI	10	401	14	112	35	Rejected	pH, TH and Magnesium Hardness are out of range.
VII	7.6	650	14	108	45	Rejected	TDS, TH and Magnesium Hardness are out of range.
VIII	7.2	400	26	129	28	Rejected	TH is out of range.
IX	7.0	230	23	56	20	Accepted	Data meets the expected quality standards.
X	6.9	78	24	45	28	Accepted	Data meets the expected quality standards.

EXPERT SYSTEM FOR QUALITY CONTROL

Success: Your data meets the expected quality standards

Your result for PH sample is: 6.5

Your result for Total dissolve solids sample is: 66

Your result for Conductivity sample is: 15

Your result for Total Hardness sample is: 30

Your result for Magnesium Hardness sample is: 30

Date
Signature

Print or Save as PDF

Figure 4: Expert System's Result for Sample I

EXPERT SYSTEM FOR QUALITY CONTROL

Rejected: Your data doesn't meet the required quality standards.

PH sample 12 is out of range.

TDS sample S40 is out of range.

Magnesium Hardness sample 40 is out of range.

Date
Signature

Print or Save as PDF

Figure 5: Expert System's Result for Sample V

Dissolved Solids (TDS) above 500 were rejected, Conductivity values exceeding 1000 were rejected, Total hardness values above 100 were rejected and Magnesium hardness values above

30 were rejected. The ES effectively ensured water quality within safe limits for human consumption, preventing samples with excessive

levels of contaminants or undesirable properties from being deemed fit for consumption

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V. Conclusion

This study successfully developed an ES for quality control management in the water processing industry. The system, built using JavaScript, features a user-friendly interface and integrates advanced algorithms with industry expertise. The knowledge base was developed through a comprehensive review of industry guidelines, expert opinions and scientific literature. The system's effectiveness was validated through a case study involving the analysis of 10 water samples, demonstrating its ability to accurately evaluate water quality and flag samples outside acceptable ranges.

The ES has the potential to enhance quality control management in the water processing industry, ensuring the delivery of high-quality products and safeguarding consumer health. Its application can be extended to other industries, such as food processing, where quality control is critical. Future research can focus on integrating additional features, such as machine learning algorithms, to further enhance the system's capabilities. Overall, this study demonstrates the feasibility and effectiveness of ES in quality control management, highlighting their potential to transform the industry.

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