Quality Assurance of IoT based Systems using Analytic Hierarchy Process

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Abstract: The Internet of Things (IoT) has attracted wide attention in various industrial and customer applications. In 2021 there will be approximately 50 billion devices connected to IoT across the globe. With the increasing globe, the question arises to focus on quality assurance of the IoT applications. The performance of the IoT-based systems is the directly dependent quality of hardware and software. Quality assurance (SQA) is a crucial factor for maintaining the quality of service of IoT-based applications. The existing quality models mainly focus on the software aspects of the applications. This paper presents an Analytic Hierarchy Process (AHP) for the quality evaluation of IoT applications which comprises software as well as hardware. An agriculture field monitoring system application based on Wireless Sensor Network (WSN) and IOT is considered to evaluate the proposed quality model. We present simple Fuzzy logic algorithm for the agriculture field monitoring. The performance of the proposed quality model is evaluated against various quality attributes such as functional suitability, compatibility, maintainability, usability, performance efficiency, security, reliability, and portability. The proposed SQA approach gives a consistency index and overall quality measure of 0.061 and 0.7564 respectively. It has shown significant improvement over the previous state of arts such as Grey and IA-QM SQA approaches.

Keywords: Internet of Things, Quality Assurance, Analytic Hierarchy Process, Quality of Service

1. Introduction

Internet of things (IoT) is a group of various devices sensors, software, and other technologies connected over the internet for data collection, processing, and communication. IoT encompasses the hardware as well as software components [1]. IoT is used in a wide range of applications such as industrial automation, consumer application, transportation, control systems, logistics, agriculture, home automation, disaster management, energy management, environment management, military, medical and healthcare applications, food security, building automation, and security applications [2][3][4]. The Internet of Things (IoT) based systems allow users to access the remotely installed applications with ease [5][6].

IoT-based systems are facing challenges due to problems related to platform dependency, interoperability, privacy, reliability, storage, and security. In the past years, IoT-based products are mostly been released without prior evaluation of the software quality which fails to guarantee customer satisfaction [7]. The SQA can directly impact user satisfaction and market value. The IoT architecture is based on four major functionalities such as data collection and monitoring, data processing, execution, and feedback mechanism. IoT applications are entirely made up of various components. A large number of components work together to form the IoT device and network [8][9]. SQA is the process of monitoring and ensuring the quality of software. It consists of various standards and procedures which can be used for the audit and review of the software product to verify that the software attains the quality criteria of specific standard [10][11]. SQA includes a complete software development process that consists of requirements, software design, coding, source code control, code review, software management, testing, and software integration [12].

This paper presents, software quality evaluation of the IoT-based agriculture field monitoring application using an analytical hierarchy process. The proposed IoT-based system predicts the water management based on soil moisture, PH, and temperature. Figure 1 illustrates the detailed process diagram of the proposed approach. It considers the performance of various quality metrics such as functional suitability, compatibility, maintainability, usability, performance efficiency, security, reliability, and portability for the quality evaluation of the software module of the IoT-based plant leaf disease detection.

The rest of the paper is structured as follows: Section II gives the related work on software quality assurance of the AHP in brief. Section IV describes the experimental results and case study in detail. Finally, section V provides the conclusion and future direction of the proposed work.

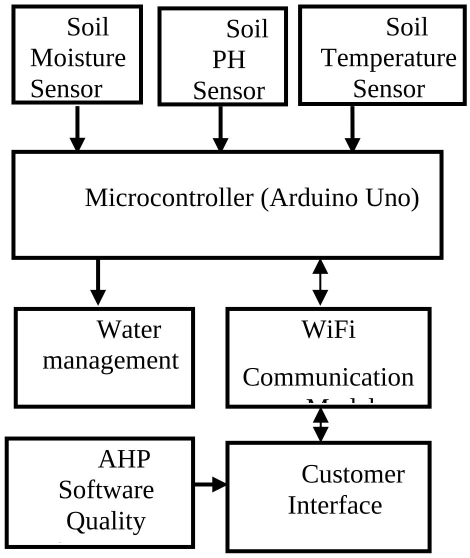


Figure 1. Detailed process diagram of the proposed system

2. Related Work

Various techniques and models have been presented in the past for the software quality assurance of IoT-based systems. Kim [13] presented four new quality metrics to extend the ISO 9126 quality measures such as functionality, reliability, efficiency, and portability. It has shown better relevance to complex IoT-based applications. IoT-based systems are suffering consistently from user's privacy, security, trust, interoperability, integration, limited connection, legislation, performance, and several configurations [14]. Tambotoh et al. [15] have given an overview of information quality attributes of COBIT 4.1 and ISO/IEC 25010 standards for software quality assurance of the IoT-based systems. They have formulated a relationship between various quality metrics and IoT characteristics. Gi-oug, Oh et al. [16] investigated ISO/IEC 9126 using an analytical hierarchy process (AHP) for the examination of quality assurance of the RFID-based IoT application for various attributes such as functionality, efficiency, portability, reliability, and usability. It is suggested that the evaluation of various quality metrics would help in the selection of RFID middleware components. Bruno de-Souza et al. [17] presented the SCENARIoCHECK technique based on a questionnaire module for the inspection of the quality of IoT-based scenarios. They have performed feasibility and observation studies to monitor the use of techniques and adequacy of techniques to detect the defects in IoT scenarios. In [18], the authors have improved the performance of ISO/IEC 9126 by adding security and compatibility attributes of the IoT-based applications.

Various software quality assurance metrics have been presented in the past. Most of the previous quality metrics were focusing on the functionality, efficiency, and reliability of the systems. Very little concentration has been given to privacy, portability, and security. The quality of the software is evaluated by considering the individual quality metrics of the systems; however interdependency of the various quality metrics evaluation of real time IoT based system is yet unexplored.

3. Analytic Hierarchy Process For Quality Assurance

Analytic Hierarchy Process (AHP) is a multi-attribute decision-making technique that can be employed for planning, resource allocation, selection of best alternative, and resolving conflicts. It is based on the inconsistency measure to improve the judgment. AHP process has four basic steps such as product development, derivation of weights for various quality attributes, consistency check, and model synthesis, and final quality decision [19].

In the hierarchical structure of the AHP, the goal is kept at the top first level, the second level consists of criteria or attributes, and the third level consists of alternatives. The pair-wise comparative matrix for eight software QA attributes can be given by the table. The pair-wise comparison gives relative importance to the different attributes or software QA criteria regarding the goal. In the third step, the consistency index is calculated to check whether the selected attributes can be used for the software QA evaluation [20].

The fundamental weight scales for deriving the judgments are given in Table 1. The value of judgment is given by considering the importance of each attribute concerning all other attributes. AHP considers that how one attribute is important over other attributes. Eight attributes for the software quality assurance of the IoT-based products such as functionality, performance efficiency, compatibility, usability, reliability, security, maintainability, and portability have been considered for this work. If two attributes are having equal importance then the fundamental weight is selected as 1. The weights 3, 5, 7, and 9 represents moderately preferred. The weights 2, 4, 6, and 8 describe moderate ratings related to neighboring metrics.

The random index for the various numbers of attributes is given in Table 2. Increasing the number of quality attributes, the random index also increases

Table 1 Fundamental weights of judgment

Value	**Definition**	**Description**
1	Equal	Two activities contribute equally to the objective
3	Moderate preferred	Experience and judgment slightly favor one activity over another
5	Strongly preferred	Experience and judgment strongly favor one activity over another
7	Very strongly preferred	Activity is strongly favored over another and its dominance is demonstrated in practice.
9	Extremely strongly preferred	The evidence favoring one activity over another is of the highest degree possible of affirmation
2,4,6,8	Medium	Used to represent a compromise between the preferences listed above

Table 2: Random index for various quality attribute

Attributes	3	4	5	6	7	8	9	10
RI	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

4. Experimental Results And Case Study

4.1.System Development

The proposed IoT-based agriculture field monitoring system consists of Arduino Uno Controller to control the moisture sensor (hygrometer sensor), temperature sensor (DHT11), PH sensor, wireless communication model (ESP8266 WiFi Module), and motor. Nowadays, economic growth and human development are hugely dependent upon the agriculture sector. The proposed system consist of wireless network of four moisture sensor, four temperature sensor and four four PH sensor. Fuzzy logic is uded to enerate the decision based on the multiple input variables having different ranges obtained from the sensors placed in the agriculture field [22]. The hypertext pre-processor is used to develop the webpage that can be operated through Android phones. The webpage provides facility to user to monitor and control the systems parameters. The humidity of the soil should be 20-80% and the temperature range should be 20 to 40 degrees Celsius for the good quality of the crops. The moisture value predicts the wet and dry state of soil which can be used for the water management of field.

4.2.Software Quality Evaluation of Application

Relative feedbacks are acquired from the various farmers and researchers using the customer review portal available on the webpage. The review portal consists of direct and indirect questions related to the functionality, performance of the system, compatibility issues, ease and reliability of the system, portability and acceptability on various platforms, level of security and maintainability, etc. The portal questionnaire is designed with mapping related to the various quality attributes where the weights for every question are decided using AHP weights given in Table 1. The pairwise software quality assurance comparison matrix generated from the average weights of each question is shown in Table 3. The responses from the 50 users/farmers by motivating them to use the desktop or android application for plant leaf disease detection are collected. The significance of every software quality assurance attribute is evaluated over the other software quality assurance attributes. When every attribute is mapped with itself, the weight is selected as one because of equal importance. For the quality evaluation six functions have given importance such as working of temperature sensor, working of moisture sensor, working of PH sensor, Motor control to regulate water pump, control easeness at webpage, and communication interface.

Table 3 Pairwise software quality assurance comparison matrix

Software Quality Assurance Metrics	Functional Suitability (FS)	Performance efficiency (PE)	Compatibility(CO)	Usability (US)	Reliability (RE)	Security(SE)	Maintainability (MA)	Portability (PO)
Functional Suitability	1	1/7.	1/3.	1/3.	1/3.	1/5.	1/3.	1/3.
Performance efficiency	7	1	3	3	3	5	3	3
Compatibility	3	1/3.	1	3	1	1	1	1
Usability	3	1/3.	1/3.	1	3	3	1	1
Reliability	5	1/3.	1	1/3.	1	3	1	1
Security	5	1/5.	1	1/3.	1/3.	1	1	1
Maintainability	5	1/3.	1	1	1	1	1	3
Portability	4	1/3.	1	1	1	1	1/3.	1

Table 4 Consistency ratio and consistency index calculation using AHP

	Software Quality Assurance Attribute Weight Matrix (A1)								**Cost**	**A2-weight**	**A3 =A1*A2**	**A4 =A3/A2**	**Consistency Index**	**ConsistencyRatio**
	FS	**PE**	**CO**	**US**	**RE**	**SE**	**MA**	**PO**						
FS	**1.00**	0.14	0.33	0.33	0.33	0.20	0.33	0.33	0.32	0.03	0.28	8.30	0.086	**0.061**
PE	7.00	**1.00**	3.00	3.00	3.00	5.00	3.00	3.00	3.10	0.33	2.63	8.02		
CO	3.00	0.33	**1.00**	3.00	1.00	1.00	1.00	1.00	1.15	0.12	1.09	9.00		
US	3.00	0.33	0.33	**1.00**	3.00	3.00	1.00	1.00	1.15	0.12	1.13	9.32		
RE	3.00	0.33	1.00	0.33	**1.00**	3.00	1.00	1.00	1.00	0.11	0.92	8.69		
SE	3.00	0.20	1.00	0.33	0.33	**1.00**	1.00	1.00	0.71	0.08	0.65	8.67		
MA	3.00	0.33	1.00	1.00	1.00	1.00	**1.00**	3.00	1.15	0.12	1.03	8.52		
PO	3.00	0.33	1.00	1.00	1.00	1.00	0.33	**1.00**	0.87	0.09	0.77	8.33		

Table 4 shows the Consistency ratio and consistency index calculation using AHP. For the eight quality (N=8), the cost of each quality attribute is computed using equation 1. The cost of the attribute shows the importance of the software quality attribute. The highest the cost of the attribute, the higher is the significance of the attribute for the particular IoT-based application. It is observed that performance efficiency has a higher cost and functionality has the lowest cost as shown in Table 6. The performance efficiency correlates the execution, accuracy, and concision whereas functional suitability describes the completeness and operability of the system.

$$cost = (FS * PE * CO * US * RE * SE * MA * PO)^{\frac{1}{N}} \quad (1)$$

The weights of the various attribute represent the significance of the attribute for the software quality assurance. The weights for every quality attribute are computed using equation 2. The cost and weights for distinct quality metrics are shown in Figure 2.

$$W_i = \frac{cost_i}{\sum_{i=1}^{N} cost_i} \quad (2)$$

The factor A3, A4, and λ are given by the equation 3-5 where

A1 is an original quality matrix, W stands for the weight of the respective attribute and N is a total number of attributes.

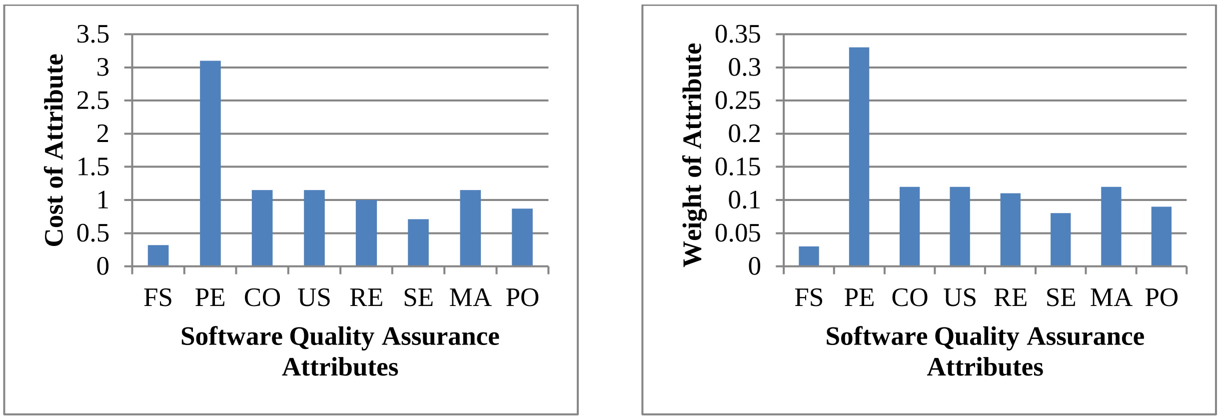
$$A3 = A1 * W \qquad (3)$$

$$A4 = A3/W \qquad (4)$$

$$\lambda = \frac{\sum A4}{N} \qquad (5)$$

The consistency index (CI) for the AHP process is calculated using equation 6. The CI represents the inconsistency of the quality attributes and it should be smaller (less than 10 % deviations from the non-random entries).

$$CI = \frac{\lambda - N}{N - 1} \qquad (6)$$



(a) (b)

Figure 2 a) Cost b) Weight of software quality assurance attributes

The quality factor for each attribute is defined using equation 7. The quality factor for each criterion considers the customization criterion for secondary attributes and n is several secondary attributes under primary attribute.

$$QA_i = \frac{\sum_{i=1}^{n} C_{ij}}{n} \qquad (7)$$

The overall quality measure of the IoT-based system for N number of primary attributes is obtained using the weight of each attribute obtained using the AHP process and quality factor as given in equation 8. Here, W_i represents the weight of quality attributes considered for the software quality assurance of the IoT-based systems.

$$QM = \sum_{i=1}^{N} QA_i * W_i \qquad (8)$$

Table 5 shows the quality factor and quality measure computation for the various software quality attribute of the proposed IoT-based agriculture field monitoring and plant leaf disease detection. The weights for the computation of quality measures are selected from the AHP process. The proposed method gives the quality measure of 0.756479 which indicates that the procedure and quality metrics considered for the evaluation of software quality of the IoT-based applications are sufficient. The performance of the proposed software quality assurance model is compared with previous techniques adopted for the software quality assurance of the IoT-based systems as shown in Table 6. It is observed that the proposed approach provides better results for a large number of quality attributes for complex IoT-based systems.

Table 5 Quality measures for various attributes

Primary Quality Attribute	**Secondary Quality Attribute**	**Description of Quality parameters**	**Quality Factors (QA)**	**Weight**	**Quality Measure (QM)**
Functional Suitability	Functional completeness	X=A/B= 6/6 =1 A= Number of functions completed.	0.9166	0.03	0.027498

		B= Number of functions stated.			
	Functional correctness.	X=A/B = 5/6=0.83 A=Number of functions correctly installed with the needed degree of precision B= Number of functions completed.			
Performance efficiency	Time behavior	X=Response Time/ Throughput/Turnaround Time/ Network Delay X=Simulation time/Expected time=5.3/6=0.8833	0.9611	0.33	0.317163
	Resource utilization	X= Number of resources used to complete IoT application X= Number of resources used to complete application / Total resources = 6/6=1			
	Capacity	X= System parameter that reaches Maximum limit which meets the requirements=1			
Compatibility	Co-existence	X= Number of IoT devices share common environment/ Total devices =2/8=0.25	0.4583	0.12	0.054996
	Interoperability	X=Number of cases where IoT Devices share information without failure / Total scenario = 4/6=0.6667			
Usability	Appropriateness recognizability	X=A/B = 4/6=0.6667 A= Functions recognized as appropriate by the user. B=All completed functions.	0.5556	0.12	0.066672
	Learnability	X=A/B= 5/6=0.8333 A= Functions learnt/ understood by user B=All completed functions.			
	Operability	X=A/B = 1/6=0.1666 A= Functions which are easy to operate B=All completed functions.			
Reliability	Fault tolerance	X=A/B =9/10=0.9 A= Number of times the system was operable even if there was a fault B= Number of times faults occurred.	0.75	0.11	0.0825
	Recoverability	X=A/B = 6/10=0.6 A= Number of times the system was recovered from fault. B= Number of times faults occurred.			
Security	Confidentiality	X= Percentage that application works against illegal access = 90% =0.9	0.7333	0.08	0.058664

	Integrity	X=Percentage that application works against illegal modification in the system =60 % =0.6			
	Availability	X=Percentage that application works against denial of service attack =70% =0.7			
Maintainability	Reusability	X=Number of other systems where components are reused / Total systems = 6/6=1	0.6666	0.12	0.079992
	Modifiability	X=A/B =2/6= 0.3333 A= Number of modified functions without degrading performance. B= Number of modified functions.			
Portability	Adaptability	X= Percentage with which system can be adapted to changes = 80%	0.7666	0.09	0.068994
	Installability	X= Percentage with which system can be installed/uninstalled in a specific environment =70 %			
	Replicable	X= Percentage with which system positively work with replaced component = 80%			
Overall Quality Metrics					**0.756479**

Table 6 Comparison with previous approaches

Parameter	**Grey [23]**	**IA-QM [13]**	**Proposed Approach**
Definition of quality attributes	Medium	High	High
Number of Quality Attributes	Low	Low	High
Description of Quality attributes	Low	Medium	High
Quality evaluation procedure description	High	High	High
Measure of Target	Low	Medium	High

6 Conclusion

Thus, this paper presents the evaluation of software quality assurance of the IoT-based system using an analytical hierarchical process. Various quality attributes such as functional suitability, compatibility, maintainability, usability, performance efficiency, security, reliability, and portability are evaluated for the software module of IoT-based agriculture field monitoring using moisture, temperature and PH sensor. The performance of software quality assurance is evaluated using the AHP process has given a consistency ratio of 0.061. It shows that the proposed software quality attributes are sufficient for the evaluation of the software quality of the proposed IoT-based system. In the future, a novel quality standard can be proposed which will consider the hardware quality attributes. The performance grading of various software quality attributes can be evaluated by combining the quality measures responses obtained from the software testing level, device level, and customer feedback. It is intended to propose the SQA analysis for the various IoT-based products which are available at online shopping portals.

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