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Design of Automatic Security System Based Internet of Things at the Museum

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Abstract

This research aims to determine the procedures for developing an Internet of Things (IoT)-based Automatic Security System as a security device for museum objects and to test its feasibility based on user feedback in museums. The Design Thinking model used consists of five stages: Empathize (understanding the user's perspective), Define (gathering information on the encountered problems), Ideate (generating innovative ideas), Prototype (creating a prototype of the obtained ideas, ensuring the functionality of each device feature, and validating the product through expert judgment for feedback and product revision), and Testing (evaluating the system's feasibility using Usability standards based on ISO/IEC 9241-11, focusing on Effectiveness, Efficiency, and Satisfaction with user involvement). The research results indicate that the IoT-based Automatic Security System has met optimal outcomes based on Usability aspects, namely: the Effectiveness analysis showed a ratio above 100% with a Very Effective level of achievement; the Efficiency aspect analysis received user feedback with a device usage rate of 1.35 goals per second; and the Satisfaction analysis, using the System Usability Scale (SUS) questionnaire, scored 78.25, indicating an Excellent level, suggesting that the system is worthy of use.

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INTRODUCTION

A museum is an institution whose function is to preserve, collect, care for, study, and exhibit objects that have historical, cultural, artistic, or scientific value [1]. These objects can be artefacts, paintings, sculptures, ceramics, textiles, fossils, biological specimens, or other objects that have important value. Museums are often used as a place for education, research, and scientific development. In establishing a museum in accordance with government regulations, several conditions must be met, one of which is to have protection, including rescue and security for its collections. According to Makarim, only 8% or around 39 museums meet museum standards at level A (Very Good) out of 439 museums in Indonesia [2]. A museum gets its museum-type rating after museum standardization, in which the assessment includes three aspects, namely vision and mission, programs, and management using the value weight system assessment method [3]. Lack of attention to one aspect of management, namely security at the museum, can have a serious impact on museum collections, the museum itself, and visitors. Some of the impacts that may occur due to lack of attention to the museum, such as damage to collection objects caused by humidity and inappropriate temperature settings, eventually cause mould to form on the museum's collections and walls. In addition, these historic objects are often the target of theft and damage, which threatens the continued existence and preservation of the culture and history contained therein. Therefore, proper security systems need to be implemented in museums to protect historical objects from theft and damage. Museums in Indonesia have a long history of theft of museum collection objects, which has not been prevented, starting from the case of Kusni Kasdut in May 1961, who stole

11 diamonds at the Museum Nasional to the latest in 2022, which occurred at Lapawawoi Museum, Bone, Sulawesi Selatan which lost 95 % of the museum's collections which are the legacy of the Bone Kingdom such as weapons, ceramics, ancient coins, tableware, and ceremonies, to royal stamps. A very high number for the loss of historical objects; one of the reasons is due to the lack of a proper security system for museums [4]. In addition to theft, damage often occurs, such as the destruction of the Al-Quran collection from the Kabupaten Kampar at the Museum Daerah Riau. According to Inara, humidity is one of the causes of damage to the collection of the Museum Daerah Riau [5].

In the digital era, the development of Internet of Things (IoT) technology has provided many conveniences and advantages in various aspects of human life, including in the field of security. The concept of IoT allows various devices to connect and communicate with each other via the Internet without having to involve human intervention [6]. IoT technology has opened great opportunities for the development of automatic security systems that can monitor and protect historical objects in museums. An IoT-based automated security system allows users to remotely monitor and control historical objects via electronic devices such as smartphones or tablets. Sensors are an important component in developing an IoT-based automated security system for museums. The nature of the sensor is to sense and convert these measurements to digital [7], [8]. Sensors connected to the IoT network can assist in monitoring the environment and condition of collections of historical objects in museums in real-time so that they can provide early warning if there is a situation that threatens these objects. This research uses several sensors to prevent theft and damage to museum objects, such as a fire sensor, which has the main function of detecting any fire anomalies that appear or enter the museum object storage box, which allows a fire to occur in the museum. Although, according to the regulation concerning fire prevention and control units in the workplace, it is stated that museums are classified as a mild fire hazard level, the denser the collection of objects in a museum also poses a threat to fire risk [9]. In several cases, fires have occurred in museums in Indonesia, such as what happened at the Museum Bahari, Jakarta Selatan, which occurred on January 16, 2018, after investigation it turned out to be caused by an electrical short circuit that caused a small fire in flammable objects which eventually scorched many of the collections [10]. The effectiveness of security at museums, reducing operational costs, keeping museum collection objects intact, and protecting them from extreme conditions [11]. Therefore, the development of a sensor-based automatic security system at the museum needs to be carried out to maintain the security and safety of historical objects on display in the museum. In this research, the development of a sensor-based automatic security system at the museum is carried out by utilizing IoT technology and using the ISO/IEC 9241-11 standard as an assessment standard at the product validation stage by experts and the feasibility testing stage by users so that the development of an automatic security system Internet of Things based in the museum is expected to provide solutions to existing problems and still meet the aspects of Effectiveness, Efficiency and Satisfaction in maintaining the security of historical objects on display in the museum [12].

The IoT security system's effectiveness relies on integrated wireless communication technologies, enabling an affordable solution with extensive wireless capabilities [13]. Moreover, the researcher has incorporated a user-friendly software platform and a custom security system equipped with five sensors and an ESP32-CAM module. In this research, each hardware component was customized and programmed using the Arduino IDE software with a program to ensure the accuracy and reliability of the IoT security system. System architecture as shown in Figure 1, the system relies on the first sensor, namely IR Obstacle Avoidance to detect movement, IR Flame Detection Sensor to detect fire anomalies, DHT11 Sensor to determine temperature and humidity, FC-37 Raindrop Sensor to detect water anomalies, MQ-135 sensor to detect smoke and dangerous gases for museum collection objects when each sensor detects an event anomaly, it will trigger a high signal sent via input/output (GPIO) and produce an alarm output from a buzzer and LED. This high signal drives the execution of certain code on the Arduino Nano board operating system. The code allows the ESP32-CAM module to capture images, while the Telegram API is used to send notifications to users along with related photo results.

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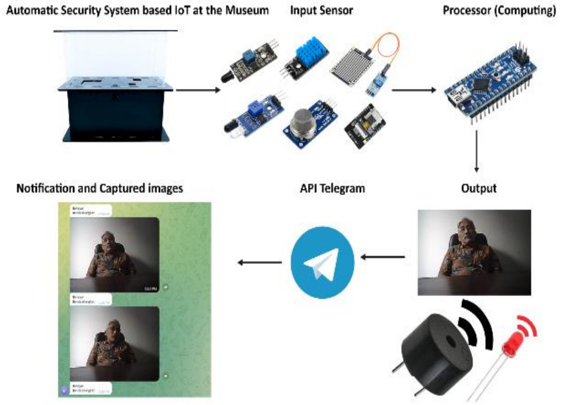

Figure 1. System architecture

METHODS

Empathize

Based on observations made during research at the Museum Keris Nusantara, several data were obtained according to each different view. In the process, interviews were conducted with three informants who worked as museum guides for the Keris Nusantara Museum.

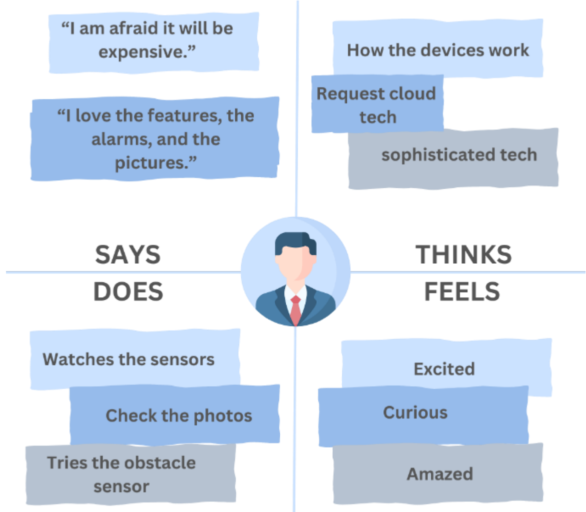

Figure 2. Museum guide 1

As can be seen in Figure 2, which shows that Museum Guide 1 thinks that the tool is not only too complex but has effective features; besides that, it feels excited and curious about how the tool works by repeatedly testing the sensors and cameras on the tool.

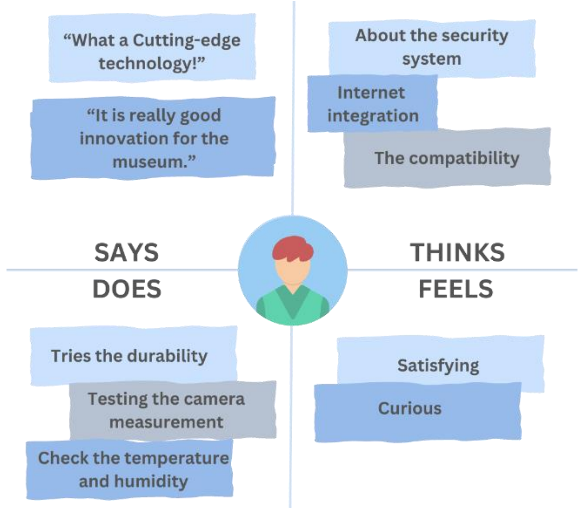

Figure 3. Museum guide 2

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The Empathy map of Museum Guide 2, which can be seen in Figure 3, shows that Museum Guide 2 considers the sensor layout to be correct and very complex. Museum Guide 2 is also proud to have this tool as a museum guide, as it will be of great help.

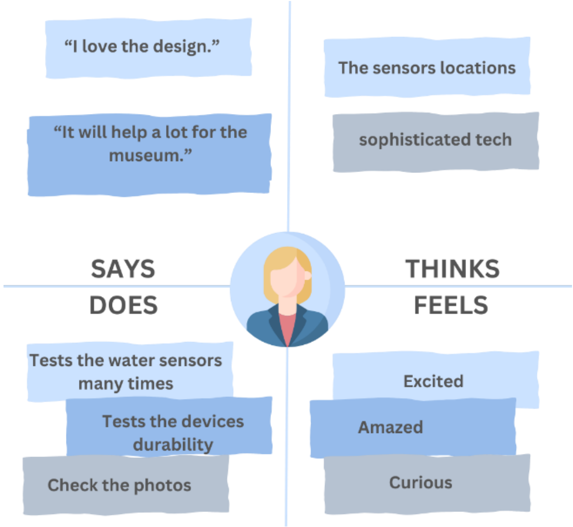

Figure 4. Museum guide 3

As can be seen in Figure 4, Museum Guide 3 is very satisfied because all sensors and cameras function very well, but it would be better if the container used is bigger so you can add lots of sensors.

Define

In the process, the researcher divides the users into several characters, such as Preferences (personal data), Problems (frustration), Desires (goals), and Aspirations (features) [14]. The following is a character illustration of each user.

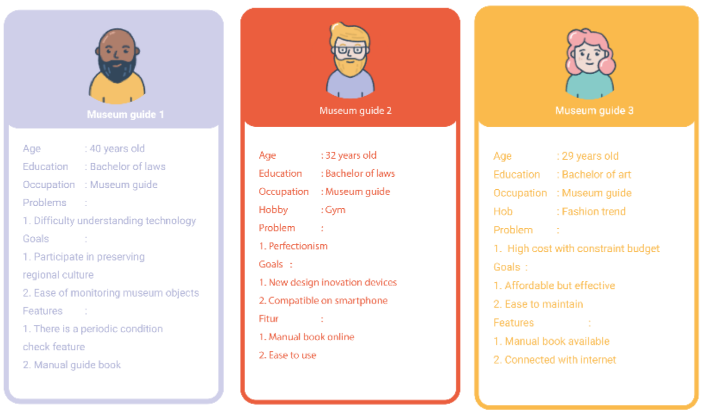

Figure 5. Museum guide 1, 2, 3

The results of the User persona method show several similarities in professional aspects such as museum guide, undergraduate level education, goals, namely wanting and needing manuals in operating these devices, and ease of use of devices in supervising museum objects.

Ideate

The results of the define stage are then carried out by methods to help generate new ideas and solutions to existing problems in a more structured and centralized way; then, the Brainstorming method is created; the following is an illustration [15].

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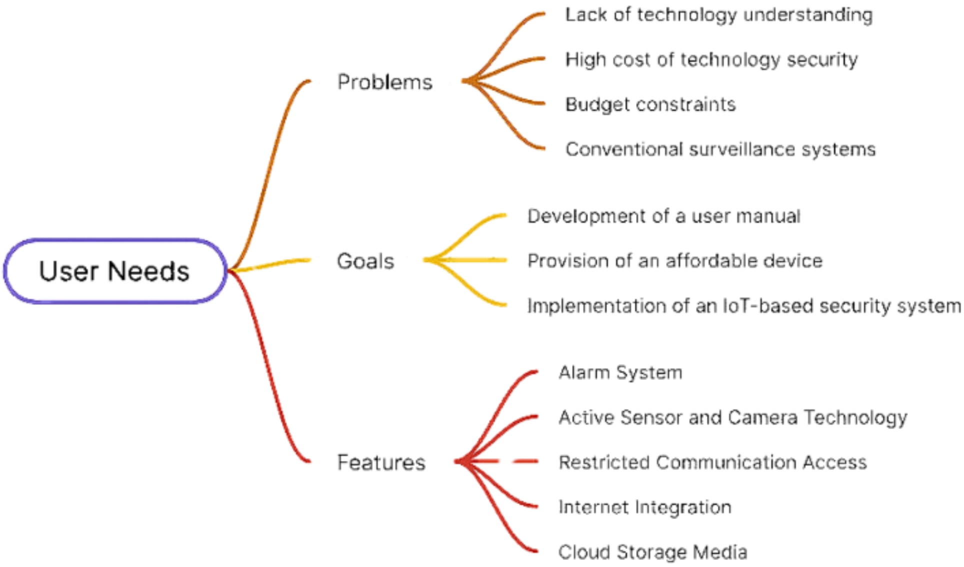

Figure 6. Brainstorming

Prototyping

At this stage, the researcher creates a model or prototype of an Internet of Things-based Automated Security System with reference to the problem-solving aspects of the problem, features, and user desires [16].

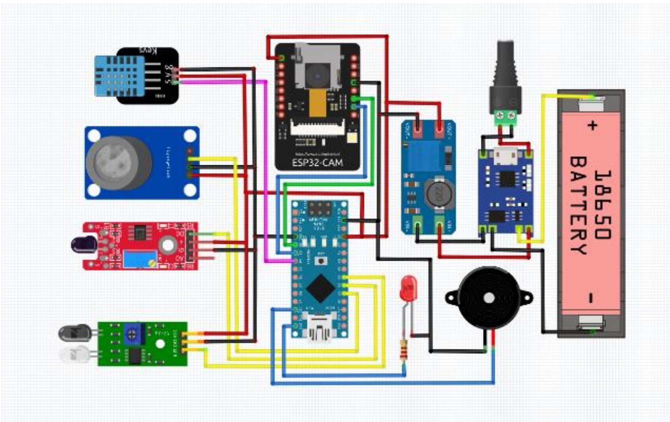

Figure 7. Scheme diagram

The design plan in vector form, which can be seen in Figure 7, will be used as a place or container for placing the device. There are two boxes in the order of the detachable model: the bottom box as a container box for the device scheme and the top box as a place-to-place museum collection object.

Figure 8. Box

After going through the vector design stage, then printing with 3mm acrylic material with a size of 24x12x10cm, cutting is done using a laser and arranged into a container for an Internet of Things-based Automatic Security System device.

Expert Judgement

The constructed prototype underwent device validation conducted by Subject Matter Experts, who are instructors of the Internet of Things course. Based on the expert judgment form, the evaluation of the IoT-Based Automatic Security System for Museum Artifact Protection reveals several important insights regarding the system's usability, functionality, and ease of use. Overall, experts found that while the system has strong functionality and useful features, there are aspects that could benefit from further refinement. For instance, responses to statements like "I find the system somewhat difficult to use" and "I find the system confusing" suggest that the system may be challenging for some users and could benefit from enhancements in user-friendliness and clarity. Despite this, the core features, such as sensors and alarms, were positively received, indicating that the main functions of the system are operating effectively and as intended. The validation affirmed that the device is deemed suitable for use and is anticipated to be frequently utilized by experts [17].

Testing

At this stage, the system testing is carried out after all sensor components and modules have been built and integrated. The main purpose of system testing is to ensure that the entire system functions properly and meets predetermined requirements or specifications. Then, do the calculations to find out the percentage of success of the sensors and modules based on the percentage formula according to follows [18]:

$$P = \frac{f}{N} x100 \ \%$$

P = Percentage of Success or Failure
f = Number of successful or failed tests
N = Total trials

Table 1. Percentage

Percentage	Result
> 76%	Good
56 - 75%	Enough
40 - 55%	Not Good
< 40%	Bad

IR Flame Detection

In accordance with the test results, which can be seen in Table 2, it shows that in the first experiment, the fire sensor detected an anomaly event by providing a fire stimulus to the IoT device, generating a sound notification from the Buzzer and sending a visual notification to Telegram with photo results, even though it was delayed once but still works.

Table 2. Result of flame detection testing

Number of testings	Range (cm)	Buzzer	LED	Notification	Photo	Information
1	1	Active	Active	Sent	Delay (2 sec)	Success
2	2	Active	Active	Sent	Sent	Success
3	5	Active	Active	Sent	Sent	Success
4	6	Active	Active	Sent	Sent	Success
5	7	Active	Active	Sent	Sent	Success
6	8	Active	Active	Sent	Sent	Success
7	9	Active	Active	Sent	Sent	Success
8	10	Active	Active	Sent	Sent	Success
9	11	Active	Active	Sent	Sent	Success
10	12	Active	Active	Sent	Sent	Success

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With the calculation of the following results:

Success Percentage: $P = \frac{10}{10}\ x\ 100\%$

$P = 100\%$

Success Percentage: 100%

Failure Percentage: $P = \frac{0}{10}\ x\ 100\%$

$P = 10\%$

Failure Percentage: 0%

DHT11 Humidity Sensor

In accordance with the program, if the temperature exceeds or equals 35ºC with humidity above 60%, it will produce an output in the form of a Buzzer alarm and visual notifications in the form of LEDs, Telegram notifications and photos from the ESP32-CAM.

Table 3. Result of humidity testings

Number of testings	Temperature	Buzzer	LED	Notification	Photo	Information
1	29	-	-	-	-	Success
2	30	-	-	-	-	Success
3	31	-	-	-	-	Success
4	32	-	-	-	-	Success
5	35	Active	Active	Sent	Sent	Success
6	36	Active	Active	Sent	Sent	Success
7	37	Active	Active	Sent	Sent	Success
8	38	Active	Active	Sent	Sent	Success
9	39	Active	Active	Sent	Sent	Success
10	40	Active	Active	Sent	Sent	Success

Success Percentage: $P = \frac{10}{10}\ x\ 100\%$

$P = 100\%$

Success Percentage: 100%

Failure Percentage: $P = \frac{0}{10}\ x\ 100\%$

$P = 10\%$

Failure Percentage: 0%

Raindrop FC-37

Testing the sensor by spraying water from the spray as a sensitivity test of the sensor module. The output of this sensor is in the form of HIGH and LOW logic, which means if an event anomaly is detected, it will produce a HIGH or ON output, and then it will send a signal to the Microcontroller.

Table 4. Result of raindrop testings

Number of testings	Total Spray	Buzzer	LED	Notification	Photo	Information
1	1x	Active	Active	Sent	Sent	Success
2	2x	Active	Active	Sent	Sent	Success
3	3x	Active	Active	Sent	Sent	Success
4	4x	Active	Active	Sent	Sent	Success
5	5x	Active	Active	Sent	Sent	Success

Success Percentage: $P = \frac{5}{5}\ x\ 100\%$

$P = 100\%$

Success Percentage: 100%

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Failure Percentage: $P = \frac{0}{10}\ x\ 100\%$

$P = 10\%$

Failure Percentage: 0%

IR Obstacle Avoidance

In testing the IR Obstacle Avoidance Sensor on standby, when the sensor detects a movement anomaly, it will send an input code as a HIGH condition so that the alarm will activate and send a notification to Telegram with the message "Danger!" followed by photos.

Table 5. Result of obstacle detection testings

Number of testings	Range (cm)	Buzzer	LED	Notification	Photo	Information
1	1	Active	Active	Sent	Sent	Success
2	2	Active	Active	Sent	Sent	Success
3	4	Active	Active	Sent	Sent	Success
4	6	Active	Active	Sent	Sent	Success
5	8	Active	Active	Sent	Sent	Success
6	10	Active	Active	Sent	Sent	Success
7	12	Active	Active	Sent	Sent	Success
8	14	Active	Active	Sent	Sent	Success
9	16	Active	Active	Sent	Sent	Success
10	18	-	-	-	-	Fail

Success Percentage: $P = \frac{9}{10}\ x\ 100\%$

$P = 100\%$

Success Percentage: 90%

Failure Percentage: $P = \frac{1}{10}\ x\ 100\%$

$P = 10\%$

Failure Percentage: 10%

MQ-135 Gas Sensor

Testing the MQ-135 sensor aims to determine the maximum distance that can be detected by the gas sensor and the duration of time needed to detect gas anomalies.

Table 6. Result of gas detection testings

Number of testings	Range (cm)	Time	Buzzer	LED	Notification	Photo	Information
1	1	2.30	Active	Active	Sent	Sent	Success
2	2	3.15	Active	Active	Sent	Sent	Success
3	5	6.30	Active	Active	Sent	Sent	Success
4	6	7.85	Active	Active	Sent	Sent	Success
5	7	9.20	Active	Active	Sent	Sent	Success
6	8	10.28	Active	Active	Sent	Sent	Success
7	9	12.00	Active	Active	Sent	Sent	Success
8	10	12.30	Active	Active	Sent	Sent	Success
9	11	14.50	Active	Active	Sent	Sent	Success
10	12	16.90	Active	Active	Sent	Sent	Success

Success Percentage: $P = \frac{5}{5}\ x\ 100\%$

$P = 100\%$

Success Percentage: 100%

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Failure Percentage: $P = \frac{0}{10}\ x\ 100\%$

$$P = 10\%$$

Failure Percentage: 0%

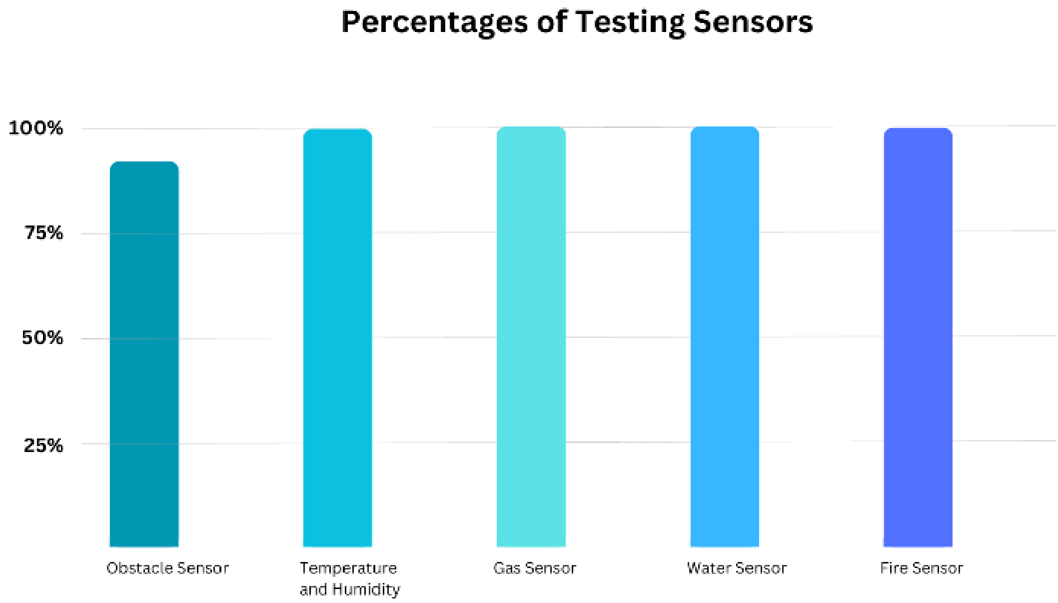

Figure 9. Testing sensors result

Effectiveness Aspect of Usability Testing

With the application of the Performance Measurement technique in analyzing data from the results of the Task Scenario by the respondent, a recapitulation is carried out by calculating the number of tasks that were successfully carried out to measure the ability of the device system to achieve user goals [19]. The results are shown in Table 7.

Table 7. Result of Effectiveness Testings

Respondent	Total Task Success	Total Task	Completion Rate Percentage
R1	12	12	100%
R2	12	12	100%
R3	12	12	100%
R4	12	12	100%
R5	12	12	100%
R6	12	12	100%
R7	12	12	100%
R8	12	12	100%
R9	12	12	100%
R10	12	12	100%

Based on the usability testing results on the effectiveness aspect that has been carried out, an average value of 100% is obtained. This value indicates that the user has been able to carry out the task properly, so according to Table 7 regarding the ratio of the evaluation of the effectiveness aspect, it received a Very Effective level rating.

Efficiency Aspect of Usability Testing

Usability testing on the Efficiency aspect is measured based on the time in units (seconds) needed by users to use an Internet of Things-based Automated Security System in museums based on the Task Scenario that has been made. If there is a failure in completing the Task Scenario, the measurement will be carried out until the user gives up or exits the system [20]. Here are reference indicators for the length of time users spend.

Table 8. Time spends indicators

Total Time	Indicator
60 – 300 second	Very Fast
360 – 600 second	Fast
660 – 900 second	Slow

In testing the efficiency aspect, ten respondents were involved in using an IoT-based automated security system in museums, which had 12 tasks (Task Scenario). To measure the efficiency of the time required, the calculation of Time-Based Efficiency is used as follows:

Table 9. Time spends Task Scenario

CODE	Time spends each Task Scenario (second)											
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
R1	6	8	3	2	3	3	10	17	14	12	18	5
R2	8	10	3	3	3	3	16	18	14	15	18	6
R3	6	8	4	3	3	3	15	18	15	13	19	6
R4	8	9	5	2	2	3	18	18	17	15	20	7
R5	7	9	3	2	2	2	10	17	17	14	16	7
R6	9	12	4	2	3	2	18	17	18	16	17	6
R7	6	8	4	3	3	3	16	15	16	15	16	4
R8	6	7	3	3	2	3	14	17	16	17	15	5
R9	4	6	3	2	3	2	12	14	14	14	13	3
R10	5	6	3	2	3	3	13	15	14	12	13	3

$$\text{Time Based Efficency} = \frac{\left(\sum_{j=1}^{R}\sum_{i=1}^{N}\frac{nij}{tij}\right)}{NR}$$

N = Total number of tasks (goals)
R = Number of users (respondents)
n_{ij} = Result of task i by user j.
If the user completes successfully the task, then Nij = 1, if not, then Nij = 0
t_{ij} = Time spent by user j to complete task i.
If the task is not completed successfully, the time is measured until the user exits the task.

$$\text{Time Based Efficency} = \frac{\left(\frac{1}{6}+\frac{1}{8}+\frac{1}{6}+\frac{1}{8}+\frac{1}{7}+\frac{1}{9}+\frac{1}{6}+\frac{1}{6}+\frac{1}{4}+\frac{1}{5}\right)}{12 \text{ x } 10} = 1{,}35 \text{ goal/sec}$$

The graphic results from time-based efficiency can be seen in Figure 10.

Figure 10. TBE result

Satisfaction Aspect of Usability Testing

Usability testing on the Satisfaction aspect using the SUS questionnaire which has been distributed to 10 respondents using IoT devices. The following is the result of calculating the score for each respondent [21].

Table 10. Score SUS

CODE	SCORE (Raw)									
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
R1	5	1	5	1	5	2	5	1	5	3
R2	4	4	4	4	4	2	4	2	4	3
R3	5	1	5	1	5	2	5	1	5	2
R4	4	2	5	2	5	3	4	3	4	3
R5	4	3	3	3	3	4	4	4	3	4
R6	4	2	5	2	5	3	4	2	5	3
R7	4	1	5	1	5	1	5	2	4	3
R8	5	1	5	1	5	1	4	3	5	3
R9	4	2	4	2	4	1	4	3	4	3
R10	5	2	5	2	5	2	5	2	5	2

Table 11. Result score SUS

CODE	SCORE (Result)										Total	Score (Total x 2.5)
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10		
R1	4	4	4	4	4	3	4	4	4	2	37	92.5
R2	3	1	3	1	3	3	3	3	3	2	25	62.5
R3	4	4	4	4	4	3	4	4	4	3	38	95
R4	3	3	4	3	4	2	3	2	3	2	29	72.5
R5	3	2	2	2	2	1	3	1	2	1	19	47.5
R6	3	3	4	3	4	2	3	3	4	2	31	77.5
R7	3	4	4	4	4	4	4	3	3	2	35	87.5
R8	4	4	4	4	4	4	3	2	4	2	35	87.5
R9	3	3	3	3	3	4	3	2	3	2	29	72.5
R10	4	3	4	3	4	3	4	3	4	3	35	87.5
Average:												78.25

The line graph result of the questionnaire SUS can be seen in Figure 11.

Figure 11. Line graph result of questionnaire SUS

Based on the results of the System Usability Scale (SUS) questionnaire in Table 11, the average value reaches 78.25, which indicates that the usability of the system tested is very good and received an Excellent rating. So, it shows that the user feels the device system being tested is very satisfying. In the context of system development, an average value of SUS 78.25 can be used as a reference to measure the success of system design and development. A high score indicates that the developed system meets user needs and can provide a good experience in its use.

CONCLUSION

A museum is an institution whose function is to preserve, collect, care for, study, and exhibit historical, cultural, artistic, or scientific objects. Only a small number of museums in Indonesia meet museum standards at level A (Very Good) set by government regulation. The problem of this research is that the lack of attention to security aspects in the museum can cause theft and damage to historical objects. As well as conducting a feasibility test. The development of an IoT-based automated security system can improve security and protect historic objects in museums with ISO/IEC 9241-11 Usability testing standards. It can be concluded that the use of IoT technology in museums can increase security effectiveness, reduce operational costs, and maintain the integrity of museum collection objects. By implementing an Internet of Things-based automated security system that utilizes sensors and related technologies, museums can strengthen the protection of their historical objects, maintain the integrity of collections, and improve security for visitors.

The suggestion from this research is that it is necessary to pay more attention to the security aspects of museums to protect historical collections. An IoT-based automatic security system can be applied to monitor and protect historical objects in museums in real time because sensors connected to the IoT network can help monitor the environment and the condition of collections of historical objects in museums. Sensors such as fire, temperature, humidity, water, motion, and gas sensors can be used to detect and prevent threats to museum collection objects. Output components such as buzzers, LEDs, cameras, and Telegram notifications can be used to alert users and security personnel when a threat is detected.

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