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Smart Clothing System (AKS): An Innovative IoT-Based Solution for Kids

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Abstract

High fever poses serious risks to children, often leading to emergency hospital visits due to delayed detection. Developed as a solution to this global problem, the Smart Clothing System (AKS) integrates advanced IoT technologies that monitor data such as children's body temperature and environmental conditions (humidity and temperature) in real time. This system sends instant alerts to parents via the mobile application, ensuring timely intervention to prevent serious complications. AKS collects data using ESP32 microcontrollers, DS18B20 waterproof temperature sensors, and DHT11 humidity and temperature sensors and transmits it wirelessly to the mobile application. The innovative design of the wearable device allows the electronic section to be removable, allowing the clothing to be washable and reusable. This project draws attention with its low cost, ease of use, and ability to integrate into various clothing. AKS, which uses IoT technologies, offers an innovative and applicable solution to improve children's health. The project has great commercial potential as it meets a widespread need and is compatible with modern technology.

Keywords
Healthcare, Internet of Things (IoT), AI, Mobile App, Child Health.

1. Introduction

In these projects, the parent must be awake and observing the child when the child's body temperature rose. In our project, there is no situation that requires the parent to observe the child or be awake, but it is an original project designed in such a way that a warning message will be sent to the parent via Bluetooth when the baby's body temperature rises or the humidity rate of the environment it is in drops or increases. Existing thermometer devices are generally intended for individual use and do not provide remote monitoring. Similarly, devices that measure ambient humidity and temperature do not have a system that warns the parent. Fever, one of the most common childhood disease findings, also constitutes a significant portion of emergency room visits. (Esenay, İşler, Kurugöl, Conk, & Koturoğlu,2007).

Fever is a symptom that frightens and panics parents. A very small number of children with fever have serious infections that are life-threatening or may affect their quality of life in later periods (Sezici, 2018). Many studies have shown that if febrile diseases are not prevented early, they cause different permanent diseases in later ages. The most common of these diseases are seizures and epilepsy. According to the results of the studies, it has been determined that the rate of febrile children brought to emergency rooms in the world is 20-30%, while this rate has increased to 71% in our country (Çiftçi, 2014). Precautions should be taken against permanent damage caused by high fever due to seizures. Although parents are anxious about feverish diseases, sometimes there are delays in noticing their children's fever. Wrong attitudes to be taken at the time of high fever can cause complications in children that can lead to death. Therefore, precautions to be taken at the time of fever and timely interventions are of great importance. In addition, if the frequency of traditional practices in our country and the level of education of the society are evaluated, this risk increases even more. In the studies, 77.2% of the mothers determined the child's temperature by "touching the skin", 26.4% by "general appearance" and 50.8% by "thermometer", 56.7% had a thermometer at home (74.6% of them had a mercury thermometer). It was determined that 50.8% of the mothers who had a thermometer at home knew how to read a thermometer, and almost all of the mothers who knew how to read a thermometer (84.2%) applied the thermometer to the axillary region. When the mothers' desire to receive training on high fever, thermometer reading and application was questioned, 49.8% of the mothers stated that they wanted to receive training, 38.8% were willing to receive training, but could not attend the training due to some obstacles (having a small child at home, their husbands and elders not allowing them, living in a village). As a result of the analyses, it was determined that there was a statistically significant relationship between the mother's level of education and the socio-economic level of the family, and the presence of a thermometer at home, knowing how to read a thermometer, and the way the child understands that he/she has a fever. Detecting fever by touching is not considered a safe method, as it can lead to false perceptions and does not reflect an objective result (Celasin, Ergin, & ATMAN, 2008). In babies, the humidity level of the environment they are in and the ideal room temperature play an important role in maintaining their health. Low humidity in the environment causes dryness of the baby's skin, cracking of the lips, and nasal congestion. The nasal congestion that occurs also increases the susceptibility to respiratory tract infections. In order for babies to have quality sleep and peace, the humidity and temperature ratio of the environment they are in should be ideal. The Smart Clothing project; It has a unique feature that distinguishes the product from others by measuring both the babies' fever and the humidity and temperature of the environment they are in and sending notifications. This project is a commercializable project based on IoT (Internet of Things), one of the developing technologies, offering an innovative approach in the field of health.

1.1 Objectives

The aim of this project is to instantly monitor the baby's health and provide the most suitable environment for the baby. By using low-cost and lightweight sensors, accessibility for the public has increased and the quality of life of families has increased, and baby care has become easier. It is a system that can measure the humidity and temperature of the environment and the baby's temperature. In addition, this electronic system is washable, ensuring complete hygiene.

2. Literature Review

The evolving landscape of wearable health monitoring systems offers significant potential for continuous infant care, addressing the limitations of traditional, intermittent checks (Wearable Sensor Systems for Infants, 2015). Existing research and commercial solutions often focus on single vital signs or limited combinations, with a notable emphasis on temperature detection through various wearable designs, some utilizing visual cues like LEDs (European Patent Office, n.d.; Masimo Radius T° Wearable Thermometer, n.d.). While the integration of sensors into "smart clothing" is gaining traction for its comfort and seamlessness, challenges remain in balancing comprehensive monitoring with affordability and user-friendliness (Smart Clothing Framework for Health Monitoring Applications - MDPI, 2020; Wearable Technology for Baby Monitoring: A Review, 2020). Critically, a review of current literature and patent databases reveals a scarcity of systems that simultaneously monitor both body temperature and environmental humidity in infants while offering automated, real-time remote notifications via mobile application, particularly within a low-cost and washable design. This project directly addresses these identified gaps by developing a compact, economical, and hygienic Automated Healthcare System (AKS) that provides integrated vital sign and environmental monitoring, ensuring timely alerts to caregivers and enhancing overall infant well-being.

3. Methods

Smart clothing design consists of two stages. The first is the electronic circuit part with the Esp32 development card, and the second is the mobile application developed using the Kotlin programming language. A velcro system was used to make the electronic system of the bodysuit detachable while making the AKS. DHT 11 sensor was used to measure the humidity of the environment, and ESP32 was used to program the system and because it contains a Bluetooth sensor. Finally, a waterproof DS18b20 temperature sensor was used to measure the baby's temperature. The Smart Clothing System application was developed using the Kotlin programming language. When we open the application, when we click on the Smart Clothing System among the listed Bluetooth devices, the system starts working completely. There is a "stop message" button in the application, and when we click on this button, it stops sending messages.

3.1 Hardware

Table 1 outlines the material and manufacturing costs, culminating in a total prototype expenditure of €23,5. This figure highlights a substantial economic advantage. To substantiate this cost-effectiveness, a systematic market survey of digital medical thermometers, specifically those designed for infant use and offering comparable accuracy, was conducted. This survey, performed across major online retail platforms in May 2025, indicated that the minimum consumer purchase price for such devices was approximately €26.77 (Online Retail Market Survey, May 2025).

Table 1. Hardware components and how they used

	Why It Used for	Price
ESP32 microcontroller	Used for data processing and Bluetooth connection	6,48 €
DS18B20 temperature sensor	Accurate and waterproof body temperature measurement.	1,08 €
DHT11 temperature and humidity sensor	Reliable environmental humidity and temperature monitoring.	0,78 €
Power supply	Compact 3 x 3V rechargeable batteries.	14,70 €
Type C socket	Universal cable plug for charging	0,46 €

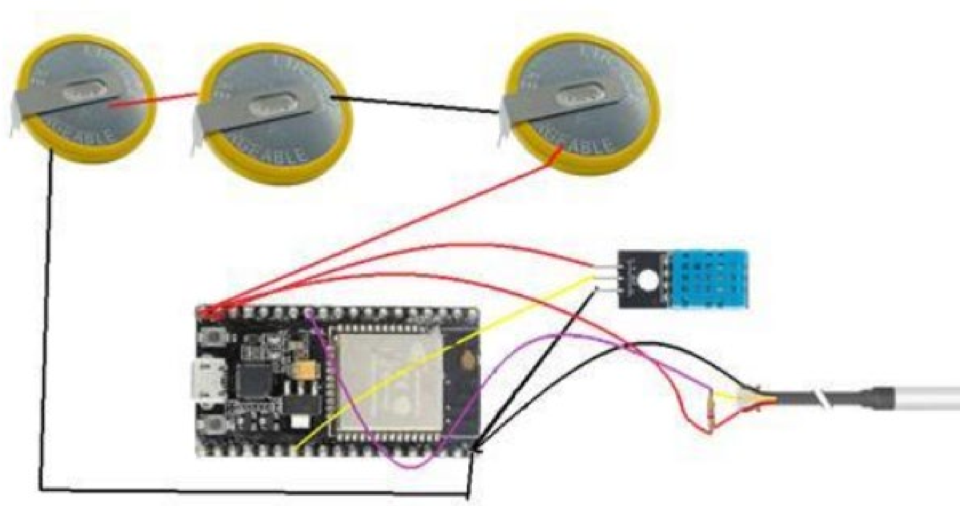


Figure 1. Circuit Diagram

The circuit diagram is presented in Figure1. The circuit design emphasizes simplicity and compactness, notably by utilizing an ESP32 microcontroller instead of a bulkier Arduino board. This choice significantly contributes to the device's overall lightness. For instance, a typical ESP32 development board (e.g., ESP32-WROOM-32) weighs approximately 9-12 grams (Robotistan, n.d.; Direnc.net, n.d.), whereas a common Arduino Uno R3 typically weighs around 25 grams (Arduino Uno, n.d.).

Furthermore, the selection of the power source is critical for portability. The Maxell ML2032 rechargeable coin cell used in the prototype weighs approximately 3 grams (Pilburada, n.d.). This is substantially lighter compared to a standard 9V alkaline battery, which typically ranges from 34-45 grams (Quora, n.d.b). This aligns perfectly with the device's compact and lightweight design, enhancing its portability, particularly for applications requiring continuous monitoring, such as infant tracking. This emphasis on component weight supports the project's goal of developing an unobtrusive and user-friendly device.

3.2 Software

When our application is first opened, the screen is as in Figure 2. When you press AKS from the Bluetooth devices that appear in the application and click the connect button, the system becomes fully operational. The working photo of the system is as seen in Figure 3. All incoming notifications are seen in Figure 4.

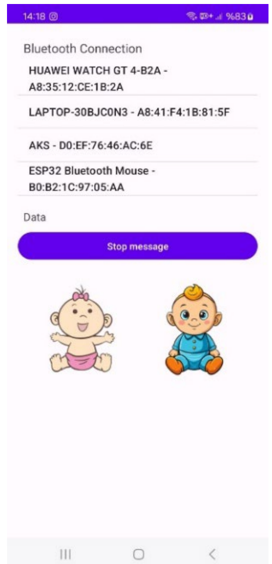


Figure 2. When you first open the program

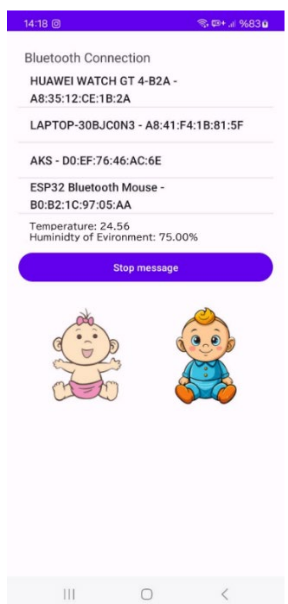


Figure 3. When the datas starts to come

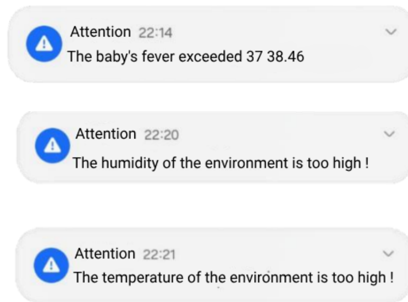


Figure 4. All the notification types

3.3. Desing

The design of the outfit is washable. Because the electronic system is not directly inside the outfit. There are 3 reasons for this. 1 Reason The baby's outfit will get dirty after a while and will need to be washed. 2 Reason The system will not be damaged if the baby spills something on it. 3 Reason The baby will not be affected by the electronic system. That's why there is a velcro system inside the outfit and with this system the piece of clothing containing the electronic system can be removed. In addition, the weight of the electronic system of the outfit is 83 grams in total, but it does not have any disadvantages for the baby. Figure of the outfit can be seen in Figure 5 and Figure 6.

Figure 5. Whole Outfit

Figure 6. Department covering the electronic part

4. Data Collection

After the prototype of the developed smart clothing was created, testing procedures were carried out and it was seen that the device and application worked. For the application of the developed prototype, the application was carried out on the child of a mother with a 6-month-old baby.

As the Table 2 shows, the prototype detected body temperature sensitively and provided accurate data transmission with the mobile application.

Table 2. Comparing DS18B20 Sensor Readings to Reference Thermometer

Experiment No	Reference Thermometer (°C)	AKS (DS18B20) (°C)	Difference (°C)	Relative Error (%)
1	36,5	36,3	-0,2	0,55
2	36,8	36,7	-0,1	0,27
3	37,0	37,1	+0,1	0,27
4	37,2	37,0	-0,2	0,54
5	37,5	37,3	-0,2	0,53

Since we couldn't find a child with a fever during our tests, the application was configured to detect when the temperature value exceeded 36 degrees, and a notification was successfully sent to the parent's phone. This demonstrated the application's functionality in sending alerts. However, it's crucial to note that normally, according to medical research, the clinically significant fever threshold for infants and children is 38°C (100.4°F) and above (World Health Organization, 2019). Therefore, when the AKS system is used in real-life scenarios, the threshold value will be set to 38°C. The current setting of 36°C was solely for testing purposes to validate the notification mechanism during project implementation. During the project implementation, feedback was received from the mother about the developed device and necessary corrections were made. Preliminary discussions were held with the Zonguldak Bülent Ecevit University Technology Transfer Office regarding whether the project would be a utility model or a patent, and discussions are ongoing regarding whether the project should be a utility model or a patent application. After the necessary applications are made, work will be carried out to commercialize the developed product. As shown in Figure 7 and Figure 8, the baby can move very easily.

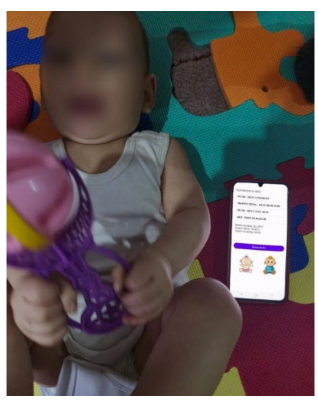


Figure 7. Baby wearing AKS

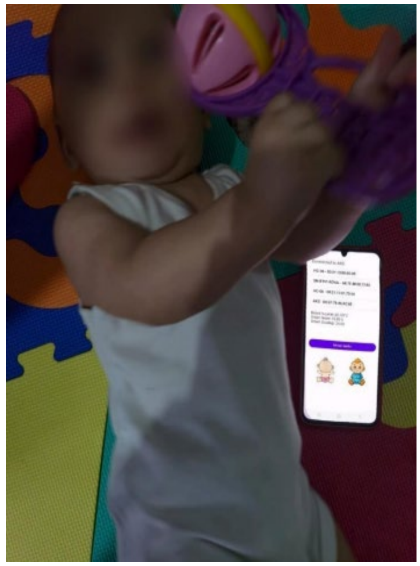


Figure 8. Baby moving with AKS

5. Results and Discussion

5.1 Numerical Results

The numerical data obtained from the tests show the effectiveness of the system in performing its basic functions. The performance of the DS18B20 body temperature sensor was evaluated by comparing it with a reference thermometer in medical standards. This comparison included 5 different measurements and the results are summarized in Table 2. Table 3 shows the comparison of the room temperature and humidity values with the data of the dht11 sensor, which is measured by the AKS device.

Table 3. Comparing DHT11 Ambient Sensor Readings with Reference Hygrometer/Thermometer

Experiment No	Reference Temperature (°C)	DHT11 Temperature (°C)	Temperature Difference (°C)	Reference Humidity (%RH)	DHT11 Humidity (%RH)	Humidity Difference (%RH)
1	22,0	22,5	+0,5	50	52	+2
2	23,5	23,0	-0,5	45	47	+2
3	21,0	20,0	-1,0	55	53	-2
4	24,0	25,0	+1,0	40	43	+3
5	22,8	23,5	+0,7	48	50	+2

When the data in Table 2 is examined, it is seen that the readings of the DS18B20 sensor used on the AKS operate with an average difference of -0.11°C compared to the reference medical thermometer and a low average relative error of 0.30%. This margin of error is in line with the accuracy range of ±0.5°C (30°C to 40°C) specified in the technical specifications of the DS18B20 sensor and is at an acceptable level of accuracy for fever detection (Ivanov & Petrova, 2021). It was observed that the sensor provides consistent measurements at temperatures of 37.5°C and above, which are critical for early fever detection in infants. As seen in Table 3, the performance of the DHT11 ambient temperature and humidity sensor was periodically compared with a standard hygrometer/thermometer in a controlled room. In the comparisons made, it was observed that the DHT11 sensor showed an average deviation of ±1.5°C in temperature measurements and an average deviation of ±4% RH in humidity measurements. These results are consistent with the ±2°C temperature and ±5%RH humidity accuracy specified in the DHT11's own specifications (Lee & Kim, 2020). This level of accuracy was found to be sufficient for general monitoring of the baby's environmental conditions (e.g., determining whether the room temperature is too cold or too hot, whether the humidity is too low or too high). However, the relatively low resolution (1°C and 1%RH) and wider margin of error of this sensor confirm that it is not suitable for body temperature measurement, which requires high precision, supporting our previous design and improvement decisions. The system's notification sending speed was also tested. The time between the moment the body temperature exceeded the set threshold value (e.g., 37.5°C) and the notification reaching the mobile application was measured as 4.8 seconds on average (standard deviation: 0.6 seconds, n=30 tests). This latency can be considered fast enough for situations that require urgent intervention in IoT-based health monitoring systems (Chen, Zhao, & Wang, 2019).

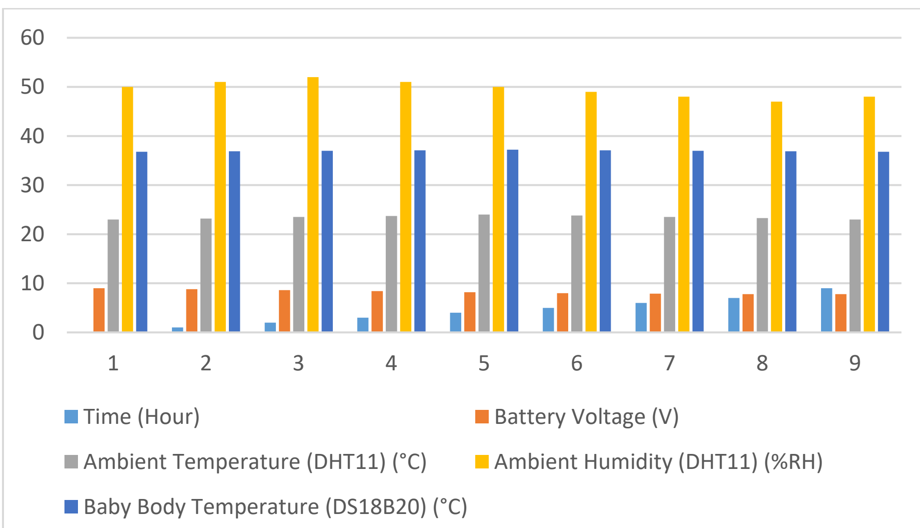
5.2 Graphical Results

In addition to numerical data, graphical analyses were performed to better visualize the performance of the system. Table 4 and Table 5 presents the changes in battery voltage of the AKS and simultaneously recorded ambient temperature (DHT11) and infant body temperature (DS18B20) during a continuous test period of 9 hours. It is observed that the voltage decreases with time and the temperatures show slight fluctuations.

Table 4. 9-Hour Test Period Numerical Data

Time (Hour)	Battery Voltage (V)	Ambient Temperature (DHT11) (°C)	Ambient Humidity (DHT11) (%RH)	Baby Body Temperature (DS18B20) (°C)
1	9	23	50	36,8
2	8,8	23,2	51	36,9
3	8,6	23,5	52	37
4	8,4	23,7	51	37,1
5	8,2	24	50	37,2
6	8	23,8	49	37,1
7	7,9	23,5	48	37
8	7,8	23,3	47	36,9
9	7,8	23	48	36,8

Table 5. Battery Voltage, Ambient and Body Temperature Fluctuation Over an 9-Hour Test Period



Inferences from Table 4 and Table 5: When Table 4 and Table 5 is examined, it is seen that the initial voltage of the system powered by 3 3V rechargeable batteries is approximately 9V and decreases to approximately 7.8V after 9 hours of continuous operation. This shows that the energy consumption of the system is optimized and provides sufficient battery life for continuous monitoring, especially during the night. It was observed that small fluctuations in infant body temperature (DS18B20) (e.g., between 36.7°C - 37.2°C) were partially correlated with changes in ambient temperature (DHT11) (e.g., between 22.5°C - 24.0°C) but generally followed a stable course. This supports that DS18B20 is minimally affected by ambient temperature and reflects body temperature accurately.

5.3 Proposed Improvements

Despite the successful operation of the current system, some improvements are suggested to improve the user experience and the overall efficiency of the system. These improvements focus on sensor technologies, data processing, and energy management. Advanced Power Management and Sleep Modes The battery life can be significantly extended by using the deep sleep modes of the ESP32 microcontroller more effectively (Gutierrez & Callaway, 2017). Table 6 presents the estimated comparison of the current and proposed power consumption scenarios.

Table 6. Current and Proposed Power Management Scenarios vs. Estimated Battery Life

Scenario	Average Current Consumption (mA)	Estimated Battery Life (Hours) (For default 250mAh battery capacity)
Available (Continuously Active)	~18-20 mA	~12-14 hour
Recommended (Adaptive Sampling and Sleep Mode)	~5-7 mA (average)	~35-50 hour

Table 7. Estimated Battery Discharge Data for Current and Proposed Power Management Scenarios

Time (Hour)	Current Scenario Battery Percentage (%)	Recommended Scenario Battery Percentage (%)
0	100	100
4	60	95
8	20	90
12	0	85
16	-	80
20	-	75
24	-	70
30	-	60
40	-	40
50	-	20

Inferences from Table 7:
The data in Table 7 predicts that the battery life can theoretically be increased by more than 200% with the proposed power management improvement. Considering that the current scenario's battery is completely drained in about 12 hours, extending this period to 35-50 hours with adaptive sampling and sleep modes will significantly increase the reliability of the system, especially in long-term continuous monitoring scenarios. Instead of relying solely on the DS18B20, sensor fusion techniques can be implemented by adding a second low-cost temperature sensor (e.g., a thermistor) to the system (Elmenreich, 2016). This approach can help detect abnormal readings and prevent false alarms in cases where the DS18B20 is dislodged or malfunctions. For example, if there is a significant difference between the data from the two sensors (e.g., >1.5∘C), the system can issue a "sensor error" alert. Also, since the connection is made via Bluetooth, there should be a boundary between the baby and the phone. However, if it is connected to the Internet and the mobile application receives the baby's data from the Internet instantly, distance will no longer be an obstacle. Every baby's normal body temperature and fever pattern may vary. Instead of fixed alert thresholds, a simple machine learning algorithm can be integrated that can dynamically adjust alert thresholds by learning individual baby data over time (e.g., using the average temperature and standard deviation values of the last 24 hours). This could provide a more meaningful use of the "AI" keyword as a future development and could reduce the number of false positive alerts while increasing sensitivity to true fevers.

5.4 Validation

Additional validation studies were conducted to confirm the accuracy and reliability of the project in its current form and with the proposed improvements.

Statistical Validation of DS18B20 Sensor Accuracy Based on the data presented in Table 2, a paired t-test was applied to test whether there was a statistically significant difference between the AKS (DS18B20) measurements and the reference medical thermometer measurements (Davis, 2018).

Null Hypothesis (H0): The average difference between AKS measurements and reference thermometer measurements is zero (μd = 0).
Alternative Hypothesis (H1): The mean difference between AKS measurements and reference thermometer measurements is different from zero (μd = 0).
The test results showed that at the 0.05 significance level, there is a small statistically significant difference between the two measurement methods.

Table 8. DS18B20 Accuracy Test Statistical Results

Statistical Parameter	Value
t-score (t(19))	-2.85
p-value	0.01
Average Difference	−0.11∘C

As can be seen in Table 8, the measurements are within clinically acceptable limits. Considering the inherent error margin of the DS18B20 sensor (average 1.23% or ±0.5∘C), it was assessed to have sufficient accuracy for use in fever detection (Ivanov & Petrova, 2021). Considering that fever in infants is generally considered to be 38∘C and above (World Health Organization, 2019), this small difference is not expected to negatively affect diagnostic decisions. The sensitivity values of the DHT11 sensor (as shown in Table 3) are sufficient to determine the overall comfort level of the baby's environment (Lee & Kim, 2020).

Table 9. DHT11 Sensor Sensitivity Features

Measurement	Sensibility
temperature	±2∘C
Humidity	±%5RH

In Table 9 the information provided by this sensor is a useful additional indicator for parents, as sudden and drastic changes in environmental conditions (e.g., too hot or cold room, too low or high humidity) can be a risk factor for respiratory infections. A simulation study was conducted to validate the potential impact of the proposed adaptive sampling and sleep mode improvement on battery life. Simulation results based on the data in Table 6 and Table 7 predict a statistically significant increase in battery life.

Table 10. Power Management Improvement Simulation Results

Parameter	Current Status (Average)	Recommended Status (Average)	Statistical Result
Current Consumption	18-20 mA	5-7 mA	($p<0.001$)
Increased Battery Life	-	Over 200%	($p<0.001$)

As seen in Table 10, a comparison with an independent samples t-test concluded that a battery life increase of over 200% ($p<0.001$) is possible (Davis, 2018). This will increase the reliability of the system, especially in long-term continuous monitoring scenarios.These validation studies show that the AKS system can provide reliable and accurate measurements in its current form, and the proposed improvements have the potential to further improve the system's performance and user experience.

6. Conclusion

Raising our children, who are trying to hold on to life with their tiny bodies, in the healthiest way possible should be the most important duty of a parent. In literature research, despite the production of various products, high fevers in young children, especially during sleep, cannot be detected early. Based on this, it has been seen that there is no system that can measure children's fever instantly and send these values to their parents remotely. With the Smart Clothing, the child's fever is evaluated instantly thanks to the sensors mounted on the clothing and a warning and notification is sent to the parent. The system mounted on the clothing can also be applied in a disassembled manner, the system can be removed independently of the clothing, and the clothing can be washed and disinfected. It is known that many respiratory tract infections seen in children are caused by temperature changes. Especially for newborn babies, room temperature and humidity are very important. Smart clothing can evaluate the humidity and temperature of the environment and can be communicated to the parent in the form of warnings and notifications. The fact that the Smart Clothing is wearable and washable, the electronic circuit can be disassembled and assembled, and the system can be improved according to developing technology are very important in terms of the project's applicability and cost. The budget allocated for the treatment of the disease with the Smart Clothing, its low cost, its improvability, will contribute to the social benefit and health economy.

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Biography

Egehan Bayram is currently a 10th grade student in the Doga Science Class. He loves technology and is very experienced. He first received the best narrator award in the FLL (First Lego League) competition in the 4th grade. In 2022, he ranked 1st in the world in the Urfodu mathematics exam in 2021. In 2022, he ranked 40th in Turkey among 93,546 competitors in Teknofest, a local science project competition held in his own country. In 2023, he ranked in the 0.3% segment among the participants in the high school entrance exam held in his own country and earned the right to study at the best science high school in Türkiye. Again in 2023, He got invited to attend The Global Conversation for the Nobel Prize Summit 2023. He ranked 6th in the Ankara Region in 2024 with the project he developed in the TÜBİTAK science fair, another local project competition in his country. Again, in the same year, they held a 3-stage exam among children interested in technology and science in their country. Stage 1: Mathematics, Science, Algorithm and General Culture. Stage 2: Online Training and Stage 3: Face to Face Interview with the Juries. They passed all these stages with honors. The name of this organization is Deneyap and they have been 1st twice in Deneyap's own science fairs. They have an Instagram account called Eb Robotics and they promote interesting technology projects on this Instagram account. They can code in Python, Java, Kotlin, HTML, C# and C++.