Design of an IoT-based smart incubator that listens to the baby

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Abstract. In the industrial era 4.0, domestic baby incubator producers are facing the challenge of free trade of foreign products that will compete in innovation with the application of IoT technology. One of the opportunities that arise consciously or unconsciously at the NICU (Neonatal Intensive Care Unit) unit in Hospitals, in general, is that there are no facilities for parents to monitor the baby’s condition inside the incubator directly. The purpose of this research project is to build a prototype of an internet-based baby incubator monitoring system based on things equipped with various sensors that will send data to the server in real-time and mobile apps for monitoring facilities for parents, including the voice of the baby. This study focused on how to develop baby incubators that can listen to baby’s crying, capture the voice, and interpret it using artificial intelligence. More than 40 (forty) voice datasets were used and successfully classified into five possible terms of the baby’s condition: burping, sleepy, hungry, uncomfortable, and pain by energy signal and spectrum analysis. The benefit of this research is as a driver of innovation for baby incubator products that will support the national medical devices manufacturing company.

1. Introduction

In the industrial era 4.0, the main challenge of the product is the use of digital infrastructure where the internet of things (IoT) has been developed. IoT refers to physical devices, communication networks, medical equipment, and other items that can be connected using internet communication protocols. With the existing internet network, data will be collected and processed in a centralized server [1]. Internet of Things cases are chosen since the topic grows quicker than enactment [10].

In the health sector, national baby incubator producers are facing challenges from imported products that will have innovation with the application of IoT technology. For that, we need an internet-based baby incubator monitoring system that will encourage the creation of competitiveness.

The purpose of this research project is to build a prototype of an internet-based baby incubator monitoring system based on things equipped with various sensors that will send data to the server in real-time and mobile apps for monitoring facilities for parents, including the voice of the baby. This study focused on how to develop smart incubators that can listen to baby’s crying, capture the voice,
and interpret it using artificial intelligence. The objectives of this research are as follows: (a) building a prototype of a baby incubator monitoring system by utilizing IoT-based communication technology and various sensor modules that are already available to be sent to the server and can be accessed mobile (b) Capture and analyze the voice of the baby (crying) and decide the condition of the baby (c) Increase the safety aspect by giving a warning of problems if there are irregularities in the baby incubator environment. The benefits of the research carried out are as a driver of innovation for baby incubator products that will support the National Medical Devices Manufacturing Company.

2. Material and Methods

In general, this research can be divided into three parts, including the development of an Android-based Monitoring System, hardware and digital communication protocols, and servers and data analysis. The three sections, as the methodology of the system, can be seen in Figure 1.

2.1. Development of an Android-based Monitoring System

At this stage, Android application design was developed as a hardware module interface to the IoT Server. This entire section will establish a monitoring system that will provide an analysis of the condition of the baby in the incubator. The development of mobile apps will also include a temporary display of data that will be sent to the IoT Server. However, a more detailed and comprehensive analysis will still be performed on the server.

2.1.1. The MVC Concept. The initial design will focus on application design according to standard procedures from Google. Like, as is the application of the MVC concept, Model-view-Controller [2]. With the use of this concept, the Android program only focuses on the View section as an application view, and the Controller as a communication procedure with the webserver discussed earlier.

2.1.2. Design Application The design is based on the application layout that will be designed as needed. This will appear in each of the Controller and View sections of the application. View examples or views of the application will follow the trends of existing research [3]. The software that will be used to develop the application is Android Studio, an IDE (Integrated Development Environment), which has also become a trend, according to Google’s recommendations [4].

2.2. Development of Digital Data Communication and Hardware Modules

The developed hardware module consists of an IoT module which can be implanted or installed in a widely used Baby Incubator. Current baby incubators generally only function as regulators of room
temperature and humidity in an incubator, and some also analyze air composition. From the baby himself, some data such as body temperature, and pulse signals are also sometimes only monitored manually by the midwife in charge.

This module functions to carry out automatic data acquisition from biosensors (heart rate, body temperature, et cetera) and environment monitoring sensors (temperature and humidity of the air inside the incubator, detection of particles both gas and solid, baby voice) [5]. This data is then sent to the IoT server to be stored centrally. Furthermore, the data that has been stored on this server is further processed automatically by using the data analysis feature on the IoT server [6].

The implementation will be carried out using a low-power microcontroller system, which mainly consists of input in the form of sensors, data processing in the form of a microcontroller development board, and output in the form of a communication module (which may be integrated into the board) and LCD. In addition to developing and implementing hardware modules, it is necessary to develop methods / digital communication protocols so that data can be sent efficiently.

**Figure 2. Hardware module schema**

2.3. Development of IoT Server and Data Analysis

Data from the IoT module will be sent to the server to be processed and displayed on the monitoring page. Data will also be periodically processed with specific algorithms to get the analysis needed, such as body temperature trends, pulse patterns from infants. Other data analysis that utilizes machine learning can also be done.

In the implementation of the Internet of Things Baby Incubator Monitoring System, one essential part is the server and database subsystem, which also includes subsystems that compute and analyze collected data. This system consists of a web server composed of an interface with a sensor device on the incubator, an interface with a gadget-based display and control system (mobile device) and a PC browser owned by the user, an interface with adequate computational resources to do artificial intelligence-based analysis including baby voice, and a database to store data before sending to other subsystems for a display to users or further analysis.

On the webserver subsystem, data sent by the onboard monitor will be received and then stored in the webserver database. These data will then be sent to the computing and data subsystem analyzing machine-based analysis / artificial intelligence to assess the condition of the baby in the incubator and produce complete information that can be read and understood by parents as a basis for making decisions about the incubators being monitored.

2.4. Recording of baby voice

In order to give the smart incubator ability to listen and understanding baby’s crying, it is needed to use some recorded samples of baby voice from “Donate a cry corpus” database [7]. From this open database, more than 40 (forty) recorded baby’s voice were cleaned from background voices and ready to be used. Those cleaned recordings had been also classified into several categories. In this research, we tried to clarify those baby conditions into defined five categories: burping, hungry, sleepy, pain,
and uncomfortable. Each voice recorded is in .wav format, 128 Kbps bit rate with duration 5-7 seconds, and data size 100-120 Kb. Distribution of the voice recorded can be seen in table 1.

| Baby condition        | Number of Data (files) | Format                        |
|-----------------------|------------------------|-------------------------------|
| Burping               | 8 files                | .wav, 128 Kbps, 5-6 second    |
| Hungry                | 12 files               | .wav, 128 Kbps, 6-7 second    |
| Sleepy (Tired)        | 10 files               | .wav, 128 Kbps, 6-7 second    |
| Pain                  | 10 files               | .wav, 128 Kbps, 5-7 second    |
| Uncomfortable         | 10 files               | .wav, 128 Kbps, 5-6 second    |

The baby voice was recorded using a recording device available and stored as a digital file and transferred into a web server for further analysis.

The basic feature for classification is the energy of voice calculated for each digital signal. While the amount of energy from a signal is known as the total power in a specified time duration concerning equation (1) that has been modified, then it can be stated as follows:

\[ E = \sum_{t} (V(t))^2 \]  

(1)

And the average energy for a certain duration T, expressed as follows:

\[ E_{\text{avg}} = \frac{\sum_{t} (V(t))^2}{T} \]  

(2)

To measure the energy value of the voice signal, we must involve the window function. This is because, in the measurement of voice signal energy, we have to arrange it in certain frames. It is a standard in sound processing technology because, in general, our voice signal processing is involved with signals that are too long when calculated in the total measurement time. This phenomenon is also known as short term speech signal energy. To calculate speech signal energy, we use the basic formulation as follows:

\[ E = \sum_{t} (V(t)w(t))^2 \]  

(3)

3. Results and Discussion

As a result of voice recording after digitization can be seen as in figure 3 below. All 40 baby voice was successfully digitized and stored as digital data for further analysis.
The energy of digital signal features was then calculated for each digital data and categorized based on its classification of a baby condition. The summation of the energy of the digital signal contained in the baby voice recordings is presented in table 2.

This classification of baby condition based on voice energy contained in the sample group can be identified for detection purposes. It is even clearer when we conducted the boxplot analysis for each group, as in figure 4. As predicted, the midline and low-and-top for each group can be distinguished and, therefore, can be used to identify any baby voice and determine the baby condition.

Table 2. Energy signal on baby voices

| Baby condition   | Energy min | Energy max | Average   | Deviation |
|------------------|------------|------------|-----------|-----------|
| Burping          | 7,66       | 3.101,59   | 1.496,31  | 1249,02   |
| Hungry           | 1,99       | 2.911,56   | 539,44    | 1024,04   |
| Sleepy (Tired)   | 1,53       | 4.022,28   | 919,25    | 1134,53   |
| Pain             | 4,22       | 5.904,98   | 921,72    | 1799,01   |
| Uncomfortable    | 4,70       | 2.857,74   | 361,79    | 878,88    |

Figure 3. Example of digitized baby voice

Figure 4. Boxplot analysis of energy signal on baby voices
Another approach to classifying the baby voice based on a baby condition is by using the spectrum analysis method where the analysis was done in the frequency domain. The analysis is presented in figure 5. It can be seen that we can differentiate each type of baby voice based on the specific baby condition from its spectrum, such as cut off and width of frequency. Some of these features are useful to increase the ability of the system in determining which baby voice related to which baby condition.

Considering the result from the energy of digital signal extracted from baby voice and combining with the spectrum analysis of each voice from each baby condition group, it is possible then for the smart incubator system to determine the condition of the baby based on the baby’s voice. Afterwards, the system then reports it to parents through mobile apps. Further steps in training and testing of the system might need more and more data than we have already collected now and will be the future study of this topic. Several methods can also be utilized to analyze the baby voice, such as Hidden Markov Model [8], Neural Network or Cepstrum [9].

4. Conclusion
This study provided proof of concept on how to develop a smart baby incubator that can listen to baby’s crying, capture the voice, and interpret it using artificial intelligence technology. More than 40 (forty) voice datasets were captured and successfully classified into five possible terms of baby’s
condition: burping, sleepy, hungry, uncomfortable, and pain by energy signal and spectrum analysis. This feature is not only beneficial in making smart incubator more comfortable for the baby, but it can also enhance the monitoring functionality. The benefit of this research is as a driver of innovation for baby smart incubator products that will support the national medical devices manufacturing company.

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References
[1] Fahmi F, Nurmayadi F, Siregar B, Yazid M and Susanto E 2019 IOP Conf Ser Mater Sci Eng 648 (1) 012039
[2] Sutanto E, Romadhon CM, Kamil FR and Rahman IM 2018 Proceedings of the 2nd Int Conf Postgraduate School ICPS INSTICC 1 511–514
[3] Joshi MP and Mehetre DC 2017 IEEE Int Conf on Computing, Communication, Control and Automation (ICCUBEA) 1-4
[4] Studio A 2017 Android Studio The Official IDE for Android
[5] Patil SP and Mhetre MR 2014 ITSI Trans on Electrical and Electronics Eng 2 (1) 11-16
[6] Koli M, Ladge P, Prasad B, Boria R and Balur NJ 2018 IEEE Int Conf on Electronics Communication and Aerospace Tech (ICECA) 1036-1042
[7] Veres G 2020 GitHub Repository Available online: https://github.com/gveres/donateacrycorpus (accessed on 13 June 2020)
[8] Siregar B, Tarigan AJ, Nasution S, Andayani U and Fahmi F 2019 J of Physics: Conf Ser 1235 (1) 012051
[9] Corianti GMS, Fahmi F, Pinem M, Sihar P, Suherman S 2019 ICASI EAI DOI: 10.4108/eai.18-7-2019.2288519
[10] Marzukia P M 2018 Creative Works of Judges In Handling Internet-Of-Things (I-O-T) Cases Proceedings–ICLG 408