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Raspberry Pi-Based Smart Infant Monitoring System

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Abstract

Nowadays, one of the most significant challenges that faces many families is baby care. Parents cannot continuously observe or monitor their babies all the time. Baby monitors help in reassuring millions of parents that their children are safe. Many of baby monitors are available; however, we find that many of them do not fulfil the desired requirements. The aim of this paper is to produce a baby monitor system, which we called smart infant monitoring system that provides high-quality features. The idea is to design a system that will simplify the process of monitoring the baby by using Raspberry Pi device. The proposed system will have many features such as: displaying live video and audio, recording audio and playing it to the baby, measuring the room temperature and humidity, supporting Arabic language, determine if the baby is awake or sleep, and the most important characteristic is the ability to listen to the baby noise, which is the cry detection feature. Finally, the proposed system is tested and compared with the current system and proved its effectiveness and functionality.

Keywords: Smart infant monitoring, Raspberry PI, Measuring temperature and humidity, live video and Audio, and cry detection.

I. INTRODUCTION

The smart infant monitor system allows parents to work without any worries about their children and assist them to keep an eye on them remotely. Even so there are various products that support baby monitoring, many of them are not efficient enough. Therefore, the aim of this project is to build a low-cost system that provides high-quality features.

Internet of Things (IoTs) simply mentions to a collection of objects and devices that are connected using Internet. It provides different devices the ability to transmit and receive data on the internet simply. One of the most substantial roles for IoT is real-time monitoring so, the objective of this work is to create a smart infant monitoring system based on one of the powerful IoT devices, which is Raspberry Pi microcontroller. In particular, it will focus monitoring the baby using camera, microphone, speaker, and sensor for measuring the surrounding temperature and humidity. The challenge will be to design a system that facilitates and provide high-quality monitoring process.

This paper is systematized as follows; Section II presents the literature review of the earlier works and discusses their characteristics, functions, and disadvantages. In Section III, the proposed smart infant monitoring system is illustrated in details showing the main characteristics and features of this system. The proposed hardware model and system components are clarified in Section IV. Section V presents the comparison between the proposed work and the previous systems. Finally, the conclusion is drawn in Section VI.

II. LITERATURE REVIEW

There are number of systems available for desktops or smart phones/tablets that helps parents to monitor their babies. In the next subsections, we explain a number of these systems in terms of the functionalities and limitations.

II.I Knight's Wireless Baby Monitor [2014]

The pediatrics academy in America changed the policy declaration on infant death. It focuses, in the recent years, to provide an environment characterized by safety sleep in order to reduce the number of infant and kids' deaths [1]. The Knight's Wireless Baby Monitor was designed with some features presented by individual wireless baby monitors in a single, integrated stand-alone monitor located on top of the baby's bed with full sensors. There will be a sensor for temperature, a sensor for motion, an audio sensor to resist accidental choking and suffocation in bed. Video, audio and the temperature of the infant will be accessible through the smartphone.

The system contains three components: monitor part, alarm part and smartphone device. The main part is the monitoring in which various sensors, microprocessors, communications chip and batteries will be installed. The alarm part is a separated unit that can be placed at the end of a table, dresser, or other flat surface near an electrical socket. When the communication chip receives an alert from the monitoring part, the alarm part will flash a warning light and sound an audio alarm. The system provides a safe sleeping environment for children under the age of one year or less to reduce the infant mortality.

This system has some disadvantages:

- It is suitable just for babies that are one-year-old or younger.
- It does not measure room temperature.
- It can connect via Wi-Fi but does not provide connection through local network.
- It not allows parents to hear the baby's voice and talk to them.
- It does not provide cry detection feature.

- It does not support wake up or sleeping feature.

II.II Integrity Baby Monitoring System [2014]

The design of a GSM-based smart baby monitor system aims to provide better care for children [2]. This system observes important parameters such as body temperature, humidity status, pulse rate, movement of an infant, and the use of GSM network, this information is transferred to their parents. Parameter details can be sent to the parents with alarm so any action can be taken. The system design consists of sensors for observing important factors, LCD display, GSM interface and sound alarm all controlled by one microcontroller.

This system has some disadvantages:

- It cannot sense the room temperature and humidity.
- It does not support Arabic language.
- It does not have a mobile application
- It does not have live video and audio streaming.
- It does not provide cry detection feature.
- It does not support the awake or sleep feature.

II.III Baby Monitoring System (Middle East Technical University) [2016]

This system has some properties such as observing the baby's heart rate, measuring the baby's temperature and notifying the parents if a fever occurs and provides sleep cycle detection for detecting sleeping illnesses or showing current sleeping stage [3]. By using the statistical data from the application, it will be possible to predict the baby's sleep habits and ideal sleep conditions.

This system has some disadvantages:

- It cannot sense the room temperature and humidity.
- It does not have the ability to talk to the baby.
- It does not support Arabic language.
- It does not provide cry detection feature.
- It does not support wake up or sleeping feature.

II.IV Infant Monitoring System using Multiple Sensors [2016]

This is an efficient health observing system for babies, using sensors that can placed with baby clothes and connected by wireless connectivity [4]. This system involves completely integral Electrocardiography (ECG), temperature and Carbon dioxide (CO2) sensors everywhere around the baby's bed. This health monitoring system provides a real-time signal of any variations in the infant's status and can be used in Neonatal Intensive Care Units (NICU) and at home as well. Sudden Infant Death Syndrome (SIDS) is an unjustified death of a child under one year of age. This usually occurs without any warning signals during sleep, which is why it is difficult to identify and predict. This monitoring system will therefore be an effective method of predicting the emergence of SIDS.

This system has some disadvantages

- It does not support Arabic language.
- It does not have a mobile application.
- It does not have live video and audio streaming.
- It does not provide cry detection feature.
- It does not support wake up or sleeping feature.

II.V Automated Child Monitoring System [2016]

In this system, a Raspberry Pi device connected to static camera and the movement of the camera is made dynamic using motors and other infrared sensors [5]. The camera will be placed in the center of the room in order to cover all directions. The captured video can be streamed online and the parents can sign in to a website to access any information or updates. In addition, a GSM module is connected with Arduino which sends alert notifications whenever the camera is rotated.

This system has some disadvantages:

- It does not support Arabic language.
- It does not have a mobile application
- It does not provide cry detection feature.

II.VI Advanced Baby Monitor [2017]

This project presents the design of advanced baby monitoring system using Raspberry Pi [6]. Parameters such as humidity, temperature; movements of the infant are also monitored and the baby's sleep and sleep sequences are automatically recorded as a means by which parents could remotely observe and monitor their baby. A camera is used so that the observer and the parents can view it. This system architecture consists of sensors to monitor important parameters such as temperature and humidity sensor, motion sensor and sound sensor, which includes s microphone. The details of the parameter are sent to the parents by the alarm so if any action occurs can be taken.

This system has some disadvantages:

- It does not support Arabic language.
- It does not have a mobile application
- It does not have Live audio streaming.

II.VII Arduino Based Infant Monitoring System [2017]

This monitoring system is based on the Arduino microcontroller. It can record and store any observed information related to the infant and transmit it to a computer [7]. Staff in the neonatal intensive care unit (NICU) for diagnostic or research studies may transmit the data recorded by

the system. The observation system used in this research is equipped with an incubator containing sensors to measure the amount of humidity and heart rate. It has been connected to the baby to monitor the heartbeat in particular. The measured results, like humidity level and pulse rate are sent to the computer by the Arduino device interface.

This system has some disadvantages

- It does not support Arabic language.
- It does not have a mobile application.
- It does not have live video and audio streaming.
- It does not provide cry detection feature.
- It does not support wake up or sleeping feature.

II.VIII A Real-Time Infant Health Monitoring System for tough Hearing Parents [2017]

The system presented a real-time infant monitoring system for tough hearing parents by using mobile devices based on Android operating systems, which has sensors such as finger heartbeat, body temperature, humidity and sound detection. In addition to, a microcontroller and android devices such as smartphone and smartwatch [8]. In particular, this system is designed to monitor physiological information obtained from children and then produces alarms in case of abnormal situations. The implementation of this system depends on one of the Arduino boards which is the Leonardo board. This device is used to collect and sense information using the connected sensors and then create an appropriate alarm based on this data. Smartwatches and smartphones based on Android operating system were used to report alarms to the parent. From the implementation results, the data collected were observed and sensed by the appropriate sensors which also contain any abnormal conditions and finally the alarms were notified.

This system has some disadvantages

- It does not support Arabic language.
- The hardware connected to a mobile application via Bluetooth. This is not good due to the Poor Security, Battery Drain in the phone and short distance.
- It does not provide cry detection feature.
- It does not support wake up or sleeping feature.

From this review, we have eight different researches each support different features. Each system supports some features and missing other important ones. The target of this paper is to propose a smart infant monitoring system that overcome the disadvantages existing on these systems. In order to gather as many important features as possible in one system.

III. THE PROPOSED SMART INFANT MONITORING SYSTEM

This work aims to produce a baby monitoring system, which provides the following important features:

- Live video and audio streaming of the baby.
- Audio recording.
- Room temperature and humidity observation.
- Notifications if temperature degree higher than 23C or less than 16C.
- Determine if the baby is awake or sleep.
- Crying detection if the sound is greater than 60.
- Supporting Arabic language.
- Use mobile application to communicate with parents.

We can summarize our proposed system in Fig. 1. The figure illustrates the proposed system that consists of one of the famous microcontrollers, which is Raspberry Pi connected with some objects and devices. In the following subsections we present each feature with more details:

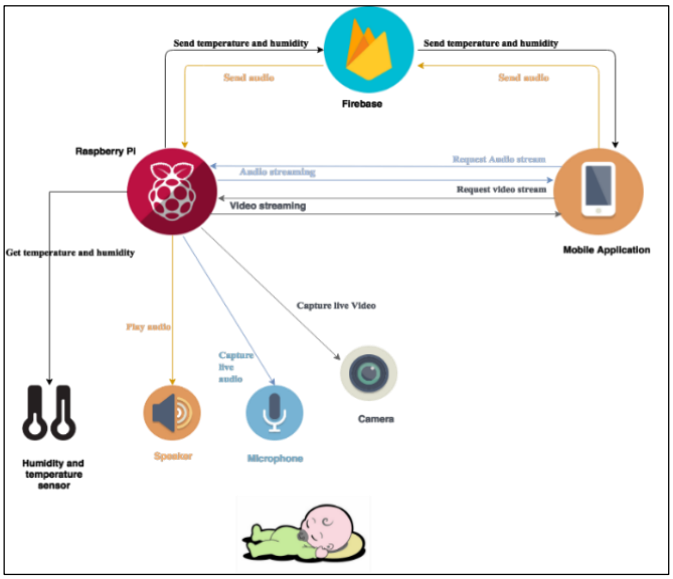

Fig. 1. The proposed smart infant monitoring systerm.

III.I Live Audio and Video Streaming

Since the Raspberry Pi device does not support a built-in mic or camera, we will use a Mini USB Microphone and a camera to plug them with the Raspberry Pi. We use a NoIR camera module (No Infrared) [9] that does not employ an infrared filter so it gives the ability to take pictures in the darkness using infrared lighting in addition to the daylight pictures.

For audio streaming, VideoLan Client (VLC) program was used to stream audio over HTTP protocol. Videolan client multimedia player software is a free charge framework with open source property. Its platform can deal with different streaming protocols and various multimedia files. To view the audio stream on the mobile application we use a player that support a real-time streaming protocol (RTSP) server protocol with the help of LibVLC SDK. Conversely, there are many tools used to stream the video. Picam software is an audio/video recorder for webcam based on Raspberry Pi, as illustrated in Fig. 2.

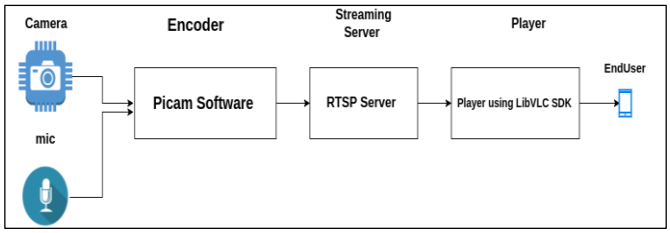

Fig. 2. Video streaming using RTSP protocol

III.II Audio Recording Feature

There are two options in this feature; the first option is recording the baby voice so that the parent will be able to upload the recorded audio to the firebase, after that it will be downloaded on the Raspberry Pi, as illustrated in Fig. 3. The second option is playing an audio music selected by the parents that stored before in the application, as shown in Fig. 4. To do this we use a specific speaker connected to the Raspberry Pi by using an audio jack.

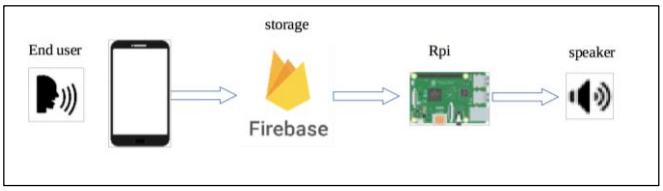

Fig. 3. Recording audio process

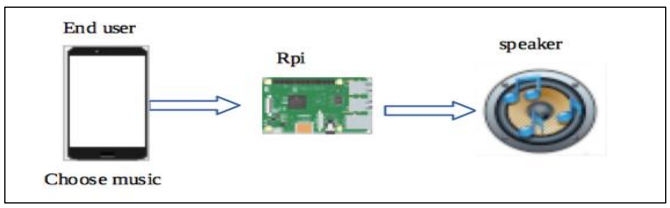

Fig. 4. Playing audio process

III.III Temperature and Humidity Features

Ultra-low-cost sensors for humidity and temperature are attached with the Raspberry Pi for measuring the surrounding temperature value and humidity change [10]. Firebase Real-time Database stores and synchronizes the measured data with NoSQL cloud database, as shown in Fig. 5. The stored data format is based on JavaScript Object Notation (JSON) and can be sent to the client within Real-time. Data remains available even if the used application is in offline mode [11].

According to [12], the temperature in the baby's room should be between 16 degree in Celsius scale and 23 degrees Celsius to help the baby to sleep safely. On the Raspberry Pi device, a python code runs every five minutes that responsible for measuring the temperature. If the temperature degree is higher than 23C or less than 16C a notification message sent to the client side through the Firebase Cloud Messaging to notify the parents about the irregular temperature level.

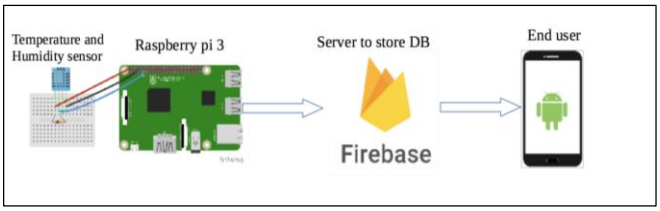

Fig. 5. Temperature and Humidity features

III.IV Awake or sleepy feature

For applying this feature, we use a TensorFlow open source library based on machine learning to classify the baby status into two categories: baby sleeping and baby awake. This can be useful for parents to display the baby status. By using the TensorFlow script, we retrain the model 4000 times applied on more than 600 images for sleeping babies and more than 600 images representing an awake baby, samples for these images are shown in Figures 6 and 7, respectively.

Fig. 6. Baby sleep samples

Fig. 7. Baby awake samples

Authors in [13] proposed a product that provides the same feature but with some differences. The notifications in this product are sent to the user through email and they display the baby stream using the web browser while in this paper, sending

notifications and displaying the baby stream through the Android Application.

During the training process, each image is reused several times and also calculate the time spent in this process each time causing the entry into the bottleneck. Therefore, it is better to store these values on the disk rather than in the cache so that they are not recalculated frequently. As soon as the bottlenecks are finished, the existing training process starts on the network layer. The script will print sequences of outputs, each presenting the training accuracy, and the validation accuracy [14]. The percentage of images used in the current training process shows the value of the training accuracy. The validation precision is the precision on a randomly selected group of images from different sets which gives a designation of the progress of the learning process.

By default, the above script will execute 4,000 training phases. Each phase selects randomly ten images from the training set, discovers their cache bottlenecks, and submits them into the last layer to obtain prediction values. Those predicted values are compared to the actual values to inform the final layer with the new weights through the process of back-propagation. As the process continues, the reported accuracy should be improved and after all the steps are done, a final assessment test for accuracy is run on a group of images that remained separate from the original training images [15].

III.V Cry Detection Feature

It is important to the parents who are far from their infants to have a quick notification in case of crying. In our proposed system, we take into our consideration this feature. Fig. 8 illustrates the flowchart for the cry detection feature.

In order to determine the actual sound level that decided that whether the sound is crying or not. Authors in [16] presents that differences in crying sound level for newborn babies and their relationship to the differences of pain ratio. They concluded that the value of the RMS (Root Mean Square) based on DAN (Douleur Aiguë du Nouveau-né) scale, which is the pain score, must be within range 0.02 (68%) to 0.01 (89%) to results that the baby is crying.

The Advanced Linux Sound Architecture (ALSA) software is a Linux-based platform and an important part of the Linux core that supports an Application Programming Interface (API) used for volume card's device drivers [17], ALSA alone does not support to share a sound card among several processes running at the same time. This involves the facility to combine the volume outputs by using special multiplexers to produce a single output stream. In order to accomplish this with ALSA there are numerous methods and techniques. These methods based on whether the volume card supports hardware collection or not, and if the processes can access the volume card by using ALSA library [18]. Every five minute the Raspberry Pi run a script to check the baby crying level. If the volume is above determined value, it sends notifications to an android application using Firebase cloud that support messaging.

III.VI Arabic Language Support

One of the main goals of this paper is the Arabic language support because there is no baby monitor that support Arabic language. However, Android OS does not directly support this behavior; by default, it uses the local language of the device to select the appropriate language dependent on Resources. The model requirements need to implement it programmatically without changing the language of the device.

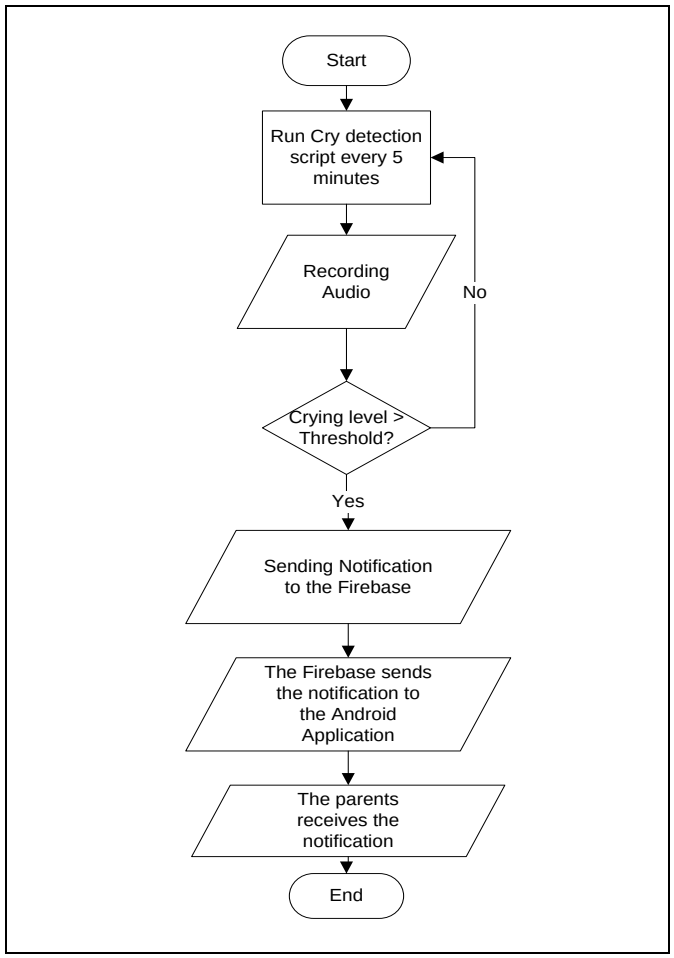

Fig. 8. Cry detection flowchart

IV. HARDWARE MODEL OF THE PROPOSED WORK

The proposed smart infant monitoring system designed and implemented by using Raspberry Pi microcontroller module and some connected sensors and devices. The hardware model for the proposed system is depicted in Fig. 9.

The system consists of the following components:

1. Raspberry Pi 3 Model B
2. Raspberry Camera Module v2
3. DHT11-Temperatyre and Humidity Sensor
4. USB Microphone
5. 32 GB Micro SD Card
6. Speaker
7. Premium jumper wires
8. Resistors
9. Breadboard

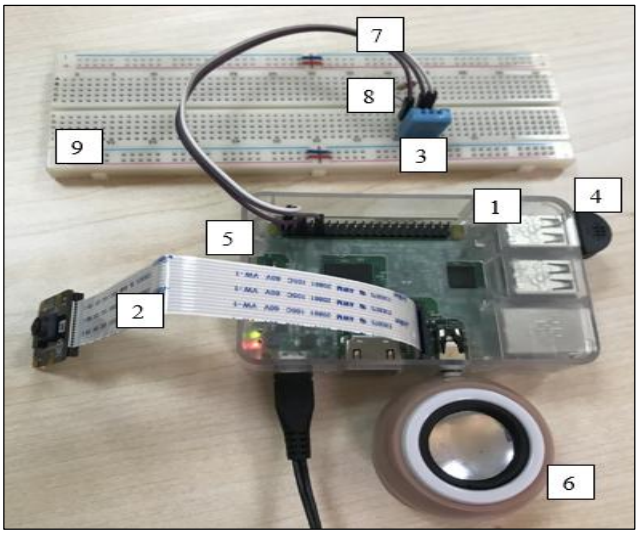

Fig. 9. Hardware model for the proposed smart infant monitoring system

As shown in Fig. 9, the above sensors, materials, and devices are connected to the Raspberry Pi microcontroller. There are three important functions performed by the Raspberry Pi device: The first one is converting the physical data like temperature, humidity, audio, video, and cry to digital data and send them to the firebase. The second function is testing the collected data in order to generate alarm based on the predefined conditions and corresponding threshold. The third function is providing the notification to the parents.

V. COMPARISON BETWEEN THE PREVIOUS SYSTEMS AND THE PROPOSED WORK

In this section, we present a comparison between the earlier systems and our proposed smart infant monitoring system. We called the earlier systems by Research 1, Research 2 …etc. As illustrated in Table 1, we have eight features; live video and audio streaming, audio recording, measuring the temperature and humidity of the room, baby is awake or sleep, cry detection, support Arabic language, connected to mobile application, and heartbeat measure.

From Table 1, some of the researches support the live video and audio streaming feature while other researches support only video or only audio or does not support this feature at all. Moreover, we notice that only one system from the earlier work supports the cry detection feature while another two systems can only detect the sound measuring without detecting cry or not. A full comparison between the earlier systems and the proposed work representing all the features and characteristics.

Table 1. Comparison between the Earlier Systems and the Proposed Work

System name	Features and Characteristics							
	Live Video/Audio Streaming	**Audio Record**	**Temp & Humidity**	**Awake / sleep**	**Cry Detection**	**Arabic Lang.**	**Mobile Appl.**	**Heartbeat**
Research 1: Knight's Wireless Baby Monitor [2014]	√	Playing only	Temperature for baby Not for Room	Sleep only	×	×	√	×
Research 2: Integrity Baby Monitoring System [2014]	Audio only	√		×	×	×	Screen only	√
Research 3: Baby Monitoring System (Middle East Technical University) [2016]	√	×		Sleep only	×	×	√	√
Research 4: Infant Monitoring System using Multiple Sensors [2016]	×	√	√	×	×	×	×	×
Research 5: Automated Child Monitoring System [2016]	√	√	×	×	√	×	Website	√
Research 6: Advanced Baby Monitor [2017]	Video only	×	√	Sleep only	Sound only	×	×	×
Research 7: Arduino Based Infant Monitoring System [2017]	×	√	Humidity only	×	×	×	PC	√
Research 8: A Real-Time Infant Health Monitoring System for tough Hearing Parents [2017]	×	√	√	√	Sound only	×	Smart watch	×
The Proposed Smart Infant Monitoring System	√	√	√	√	√	√	√	×

VI. CONCLUSION AND FUTURE WORK

The main target of this work is to propose a smart infant monitoring system that allow parents to observe their babies and communicate with them. From the literature, we found some systems used for baby monitoring but not support all the required features that the baby monitor system should have. Our proposed system in comparison with the earlier ones can support seven different features on one system and all of the required properties. Nevertheless, our proposed system does not support the heartbeat-measuring feature. Moreover, the system can send notifications to the parents in some abnormal cases such as high temperature and baby crying.

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