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Application of the Raspberry Pi 4 micro-controller for the conceptual design of the baby monitor

Abstract

The subject of the work is a conceptual design of a baby monitor. The central control system for the system is the Raspberry Pi 4 platform. In the next stages, practical aspects related to the topic of work are discussed. Selected components of the system were presented, connection diagrams between individual components were developed and the assembly process of a fully functional system was presented. Then the source code of the program controlling the operation of the electronic system was characterized. In the last stage, the method of testing and the results of the performed functional tests of the complete system being the subject of the study were described.

Key words: Raspberry Pi 4, electronic nanny, python, wireless communication.

Zastosowanie mikrokontrolera Raspberry Pi 4 do projektu koncepcyjnego niani elektronicznej

Streszczenie

Przedmiotem pracy jest projekt koncepcyjny niani elektronicznej. Centralnym systemem sterowania systemem jest platforma Raspberry Pi 4.W kolejnych etapach omawiane są praktyczne aspekty związane z tematem pracy. Przedstawiono wybrane elementy systemu, opracowano schematy połączeń pomiędzy poszczególnymi elementami, a także proces montażu w pełni funkcjonalnego systemu. Następnie scharakteryzowano kod źródłowy programu sterującego pracą układu elektronicznego. W ostatnim etapie opisano metodę testowania i wyniki przeprowadzonych testów funkcjonalnych kompletnego systemu będącego przedmiotem badań.

Słowa kluczowe: Raspberry Pi 4, niania elektroniczna, python, komunikacja bezprzewodowa.

1. Introduction

The ongoing development of electronics yields numerous benefits for society; starting with automation of industrial processes which remove the human factor from activities potentially hazardous to human health or lethal and ending with components created solely for the purpose of entertainment. Somewhere in the middle there are devices and systems the purpose of which is to aid us in everyday life. Although none electronic device can replace caring parents attempting to raise their children in the spirit of values useful in adult life the modern technology enables ensuring safety of offspring even when parents are for any reason not able to stay with their children every waking hour.

The obvious issue is ensuring that at least one of parents has a steady job in order to ensure welfare of the family. Caring for a household consists not only of raising children but also a plethora of other house responsibilities such as providing meals and maintaining tidiness.

Electronic devices cannot raise children but can at least ensure that baby's everyday nap does not mean that a parent has to spend 2 or 3 hours sitting by the crib. This time can be devoted to preparing a meal or cleaning which in case of being a parent of young children is a challenge in on itself. However, child's safety is absolutely a primary issue and therefore someone or something has to constantly stay with little children. Such expectation and challenges can be met by the latest baby monitor solution the conceptual design of which is presented in this paper.

2. The design objectives

The most important component of the baby monitor will be a Raspberry Pi 4 platform responsible for communication between appropriate off-line equipment, analysis of sensor data, interpreting the data and, if need be, reacting to circumstances by notifying the user of a potential emergency situation through a GSM communication module [8]. Sensors, an analogue-digital converter and a GSM module will be connected with the Raspberry Pi 4 platform through conductors and traces on a printed circuit board. The sole exception will be a camera which will be connected to the microcomputer through a CSI (Camera Serial Interface) port. The entire system will be mounted on an FR-4 single sided laminate on which traces will be etched in order to minimize the necessary wiring.

The remaining components of the system are:

an analogue sound sensor operating under 3.5-5 V voltage.

an ADS1015, 4-channel, 12-pin ADC converter which will convert analog signal from the sensor into a digital signal.

a PIR HC-SR501 motion sensor operating under 4.5-20 V power supply. In case of this design the motion sensor will be powered with 5 V DC voltage from the Raspberry Pi GPIO port.

an A-GSM-Shield GSM/GPRS/SMS/DTMF v.2.105 user communication module communicating with the Raspberry Pi through a serial port.

The UPS HAT module designed for Raspberry Pi providing back-up power supply in case of a failure of the main power supply.

an HD Night Vision H OV5647 camera to ensure remote surveillance over a child in real time.

a two-position "DAY/NIGHT" switch for manual selection of operating mode.

Figure 1 presents the information flow chart for the baby monitor.

Fritzing software has been used in order to visualize connections and appearance of individual components. This software enables designing electronic systems, usually based on Arduino or Raspberry Pi, in a quick and intuitive manner.

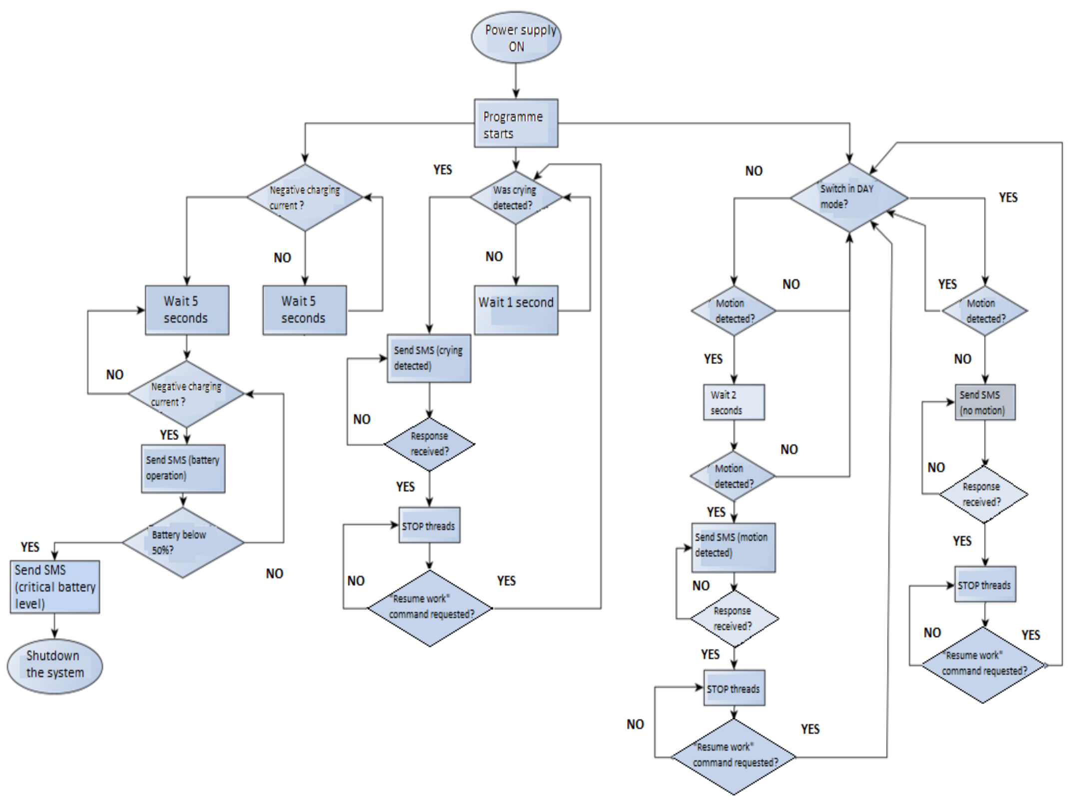

Figure 1. Chart of information flow for the baby monitor system

3. The conceptual design for a baby monitor

The conceptual design for the baby monitor has been created in AutoDesk EAGLE software which enables drawing schematics and automatically generates images of the printed circuit board which is a major amenity for designers of printed circuits. Despite a very expansive library of components EAGLE enables to easily design own, personalized components. Figure 2 presents the conceptual design of the electronic circuit demonstrating electrical connections between individual pins in the utilized components.

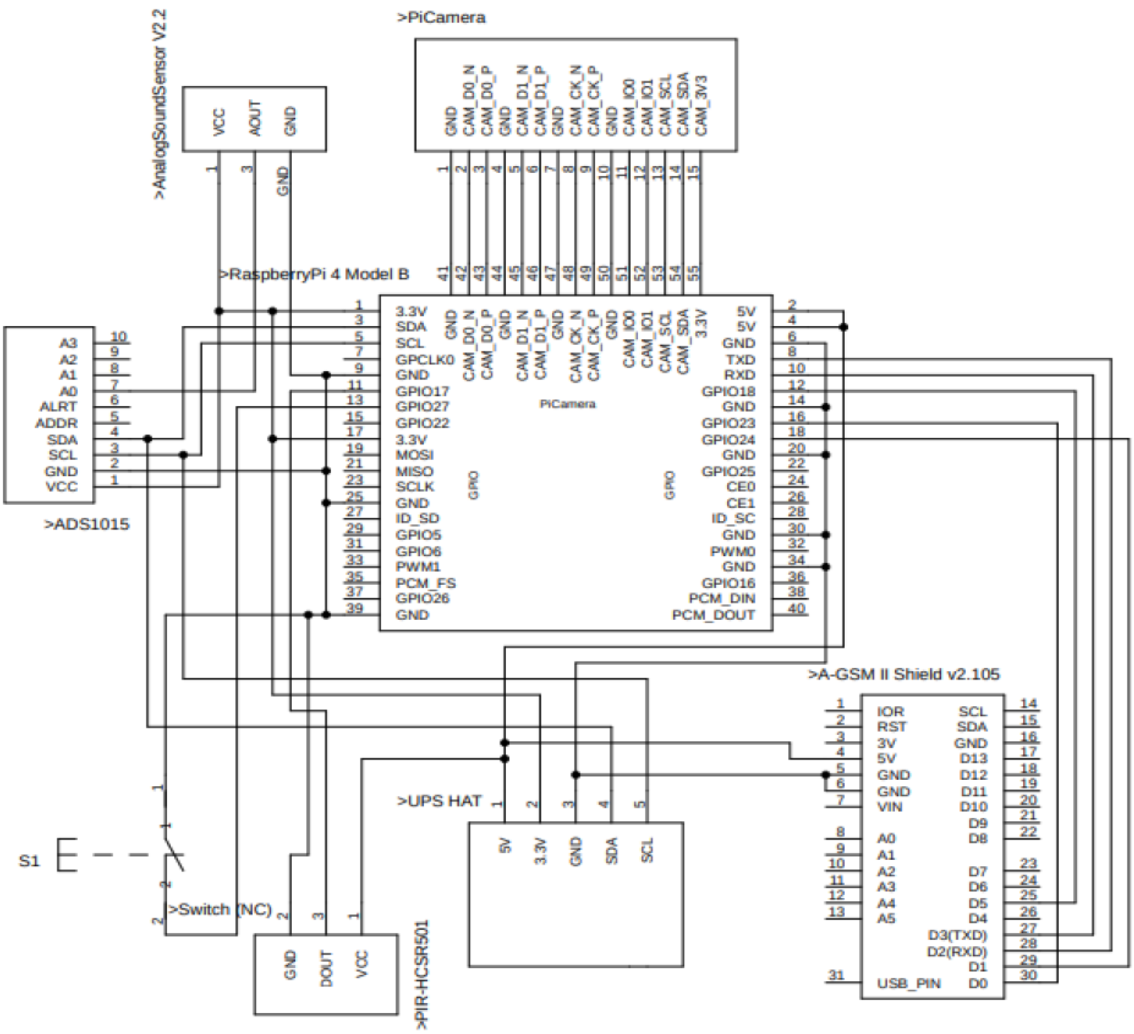

Figure 2. The conceptual design for the baby monitor system

4. Components utilized in the design

<u>RASPBERRY PI 4 micro-controller unit</u>

Raspberry Pi 4 microcomputer used to construct the baby monitor is a successor of the popular 3B and 3B+ models. Designers were able to fit the device with peripherals which increase output and simultaneously ensure that backwards compatibility is preserved.

Raspberry Pi 4 has been equipped with more powerful and efficient components which meet expectations of even the most demanding software developers and automation technicians. Broadcom 2711 is a component with four 64-bit Cortex-A71 cores with speeds up to 1.5 GHz. Changing the Central Processing Unit is related with micro-controller heat management issues and thus using appropriate radiators and casing which ensure optimal cooling are necessary.

The multi-functional nature of the system is clearly observable in regards to the primary storage. Depending on needs and projected use the platform can be equipped with three variants of primary storage, i.e. 1 GB, 2 GB and 4 GB.

The latest model of Raspberry Pi is fitted with two USB 3.0 ports, a Gigabit Ethernet port and Bluetooth 5.0 ensuring greater operating speed of communication ports.

The micro-controller has been equipped with two micro HDMI ports enabling 4k image quality.

The H.265 encoding standard allows for decoding 4k60 image and the H.264 standard enables decoding 1080p60 image and 1080p30 encoding [6]. Furthermore, the system is able of working with OpenGL ES 3.0. In comparison to previous iterations the power feed circuit has also been changed. The recommendations regarding Raspberry Pi power feed directly inform about the necessity of possessing an AC/DC adapter capable of feeding 3 A of power under 5 V voltage. Due to this fact the circuit board of the micro-controller includes a type-C USB port designed for providing power supply. Table 1 presents specification of the Raspberry Pi 4 platform utilized in this design.

Table 1

Raspberry Pi 4 technical specification

Central Processing Unit	quad-core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz
RAM memory	1 GB, 2 GB or 4 GB LPDDR4 (Depending on the model)
GPIO	Goldpin 40 pin border (fully backwards compatible)
Flash memory	microSD card port
Power supply	5 V DC via type-C USB (min. 3 A) 5 V DC via GPIO (min. 3 A) PoE (Power over Ethernet)
Graphics	H.265 (4k60 decoding) H.264 (1080p60 decoding, 1080p30 encoding) OpenGL ES 1.1, 2.0, 3.0
Communication	Gigabit Ethernet WiFi 2.4 GHz / 5.0 GHz IEEE 802.11b/g/n/ac Bluetooth 5.0, BLE 2 x USB 3.0, 2 x USB 2.0

Analog sound sensor

In order to detect sounds louder than the ambient noise of the surroundings the baby monitor utilizes an SKR DFR0034 analogue sound sensor manufactured by DFRobot Gravity.

The sensor is powered by 3.3-5 V direct current. Due to the fact that child's screams or crying are the loudest sound in the surroundings a parent will be notified via an SMS after such loud sounds are detected. Additionally such solution ensures that a user is notified not only when a child is crying but also when it is screaming as a result of e.g. becoming injured. The sensor has 2 mounting holes with diameter of 3 mm and measures 22 x 30 mm thus it is easy to install and does not require a lot of space. A major and decisive advantage of an analogue sensor over a digital sensor is the ease of adjusting the sensitivity threshold which in case of this particular system is adjusted by setting appropriate parameters in the software code. In this manner the activation threshold and the required duration of a sound with an increased volume level can be precisely determined and false alarms can be limited. The digital sensors with a built-in potentiometer for adjusting sensitivity threshold are not as precise in terms of settings' adjustment.

ADS1015 analogue-digital converter

Owing to the fact that the Raspberry Pi microcomputer is not fitted with analogue inputs and thus receiving signals from an analogue sensor is impossible an ADS1015 analogue-digital converter has been installed. The converter and Raspberry Pi communicate through I2C bus. ADS1015 is a 12-bit, 4-channel converter which allows user to expand the system with three additional analogue devices. In order to ensure proper communication the converter has to be assigned a proper address. The converter has 0x48 address assigned by default but after connecting several devices using the I2C bus to communicate some issues can emerge. Changing converter's address is realized through shorting appropriate pins, as presented in Table 2. The manufacturer also projected the option for addressing the converter through the code servicing the converter [7].

The converter has holes where GoldPin connectors are to be fitted and is connected with the Raspberry Pi microcomputer through wires. The converter operates under 2.0-5.5 V power supply voltage. In this project the converter is being powered by 3.3 V voltage from an appropriate GPIO port.

Table 2

Addressing the ADS1015 converter

Address	Required connection
0x48	ADDR -> GND (default connection)
0x49	ADDR -> VDD
0x4A	ADDR -> SDA
0x4A	ADDR -> SCL

PIR HC-SR501 motion sensor with a "DAY/NIGHT" switch

The PIR HC-SR501 motion sensor powered by 4.5-20 V voltage and generating a digital signal has been utilized to detect movement in the "NIGHT" mode and lack of movement in the "DAY" mode. The high-alert state is adjusted at the output after detecting movement. The sensor has a working range of 7 meters and thus it is sufficient for covering a single room.

Table 3

PIR HC-SR501 sensor specification

Parameter	Value
DC supply voltage	4.5 V – 20 V
Energy consumption in the standby mode	50 uA
Detection range	up to 7 m
Angle of view	up to 100°
Dimensions of module's base	32.5 mm x 24.5 mm
Diameter of the dome	23 mm
Height of the dome	18 mm
Overall height	30 mm

In order to make changing operating mode of the movement sensor possible a bistable switch has been installed. In the "DAY" operating mode the switch breaks the connection between system mass and the GPIO output on the Raspberry Pi micro-controller. In this operating mode SMS messages are being sent when the motion sensor does not detect movement within its range. After switching to "NIGHT" mode the GPIO27 pin becomes connected to the system mass; Raspberry Pi platform interprets this act as a change in the operating mode and messages are being sent when movement is detected within the range of the PIR motion sensor. The switch is adapted to work under the maximum voltage of 250 VAC and the current capacity of its contacts is 3 A.

A-GSM II Shield GSM/GPRS/SMS/DTMF v.2.105

Incorporation of a GSM communication module is the result of a possible need for notifying a user about situations possibly deviating from norm. The task of the module is to send a short text message adequate to the occurring event to a user [3]. The specification of this device enables a specific "system – user" communication. This issue is extremely important because the system will react to any deviations from norm until a parent confirms that he acknowledges that a possibly hazardous situation arose. Such solution forces a user to react immediately by sending a return SMS message to the module confirming that a parent has intervened and familiarized himself with circumstances in which a child currently is. It is a parent who decides whether the sensors should stop their operation for the duration of inspection of the room where a child currently is and who can restore normal operations of the sensors by sending a single, short message. Owing to the fact that child's safety is a priority the system solely notifies the user about any deviations from norm through a GSM module whereas the ultimate decision regarding any further actions lies solely with a parent.

F Night Vision OV5647 5Mpx HD camera

Despite utilizing sensors responsible for ongoing monitoring of a child a user has to have a possibility to remotely view the room where a child currently is. For this purpose a camera designed to work with Raspberry Pi platform has been utilized. Owing to such solution after receiving a text message a parent is able to check the factual state of a child and its surroundings on a mobile device without the need for physical presence in a given room. On grounds of this visual inspection a parent makes any further decisions regarding operation of the system and, in an emergency, goes to the room where a child is. Because using a camera ensures that a child can be monitored in real time a parent can on the grounds of the transmitted image make a decision to intervene in a situation possibly dangerous for a child before a message is sent by a GSM module. The priority for the system is ensuring child's safety and such solution excludes the possibility of interruption in information flow after a possible defect in operation of one of two sensors or a GSM module [4].

Owing to using a camera designed specifically to work with the Raspberry Pi micro-controller the processing power consumption is minimized. The 5 Mpx matrix and support for the HD 1080p mode ensure a very good quality of image and enable viewing the room where a child is in the minute details. The camera has an option for attaching two 3 W illuminators to the central segment of the camera by screws. Doing so ensures that the image is sharp and clear even in dark places. IR 850 illuminators radiate within a spectrum invisible for a human and thus operations of the system are practically imperceptible for a user. Using a knob mounted in a camera lens a user is capable of independently adjusting sharpness in accordance with conditions appropriate for a given environment. The camera is connected to the Raspberry Pi platform through a 15-pin tape plugged into the CSI (Camera Serial Interface) port.

UPS HAT

Due to the fact that the task of a baby monitor system is to ensure safety of a child under its surveillance the system itself has to be resistant to and protected against power failures. For this purpose a UPS HAT module designed specifically for working with Raspberry Pi, which ensures that the system continues to operate even after the main power supply is lost, has been incorporated into the design. The selected module is fitted with a 40-pin connector which means that it can be installed simply by slotting it into the Raspberry Pi platform. To ensure proper functioning the module is equipped with two 18650 lithium batteries with the capacity of 12,000 mAh each. These batteries are being charged by a dedicated charger with charging voltage of 8.4 V and charging current of 2 A. The UPS communicates with Raspberry Pi through the I2C bus and so it must be assigned an address not interfering with the ADS1015 converter [9]. The system will inform a user about the switch from the primary power supply to an emergency power supply as well as about the battery charge dropping to the critical level (below 50%) on the basis of such operating parameters of the emergency power supply module as battery voltage, battery charging current and percentage charge level. Table 4 presents specification of the UPS HAT module.

The baby monitor casing

The baby monitor casing was constructed from acrylic glass (polymethyl methacrylate). Individual walls were cut to specific length and width. The dimensions are as follows:

2 pieces 21 mm x 14.5 mm – top and bottom.
2 pieces 21 mm x 10 mm – front and back.
2 pieces 13.5 mm x 10 mm – both sides.

To preserve aesthetic qualities screw connections have been dropped in favor of adhesive joints. The connection between individual pieces is practically invisible and the whole system can be placed in a room without arising child's interest. Robustness of the connections is ensured by application of a cyanoacrylate adhesive to join individual parts of the casing.

Table 4
Addressing ADS1015 converter

Parameter	Value
Output voltage	5 V
Charger's parameters	8.4 V / 2 A
Communication bus	I2C
Battery	Lithium 18,650
Dimensions	56 mm x 85 mm
Mounting holes	3 mm

Operating system software

The software controlling operations of the system was written in PyCharm program. It is an integrated development environment designed for working with the Python programming language in which the code for the system has been written [1]. Intuitive interface, highlighting errors automatically and dividing errors in terms of relevance ensure that it is one of the best development environments for working with Python. Despite the limitations of the Community version of the software PyCharm offers a significant amount of useful keyboard shortcuts, a built-in terminal and automatic saving of progress – qualities which are beneficial for ease of software development.

The Motion package has been utilized to transmit the image from a camera to a phone. The camera image resolution has been set to 1920 x 1080 and frames per second were locked at 20. The camera image is sharp and in color. Furthermore, it can be zoomed in and out and the current time and date are displayed in lower left corner. Raspberry and a phone are connected to the same network. The phone is connected to the Internet through mobile data connection and after turning on a mobile Wi-Fi hotspot the Raspberry platform connects with the network automatically. The address under which the image from the camera is displayed has to be typed into the browser address bar (http://192.168.43.5:8081/). In order to avoid the need for typing in the address into the bar each time an app has been developed for Android system in the AppInventor development environment. The app includes two buttons. One of the buttons is used to go directly to the website displaying image from the camera and the other shuts down the app. In this development environment software is being created by appropriately stacking blocs realizing given functions and commands.

5. Presentation and tests of the baby monitor

The baby monitor tests cover inspecting correctness and quality of the camera image displayed on a mobile device, verifying the text messages sent by the GSM module as well as correctness of the system's response to return messages sent by a user to the baby monitor. Figure 3 presents a running baby monitor system along with a mobile device.

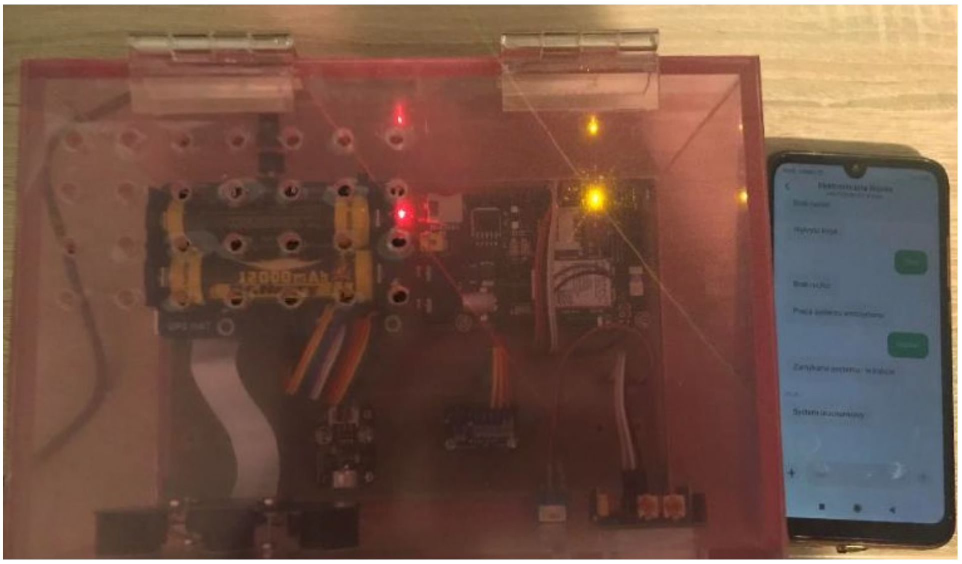

Figure 3. Baby monitor system – active and running

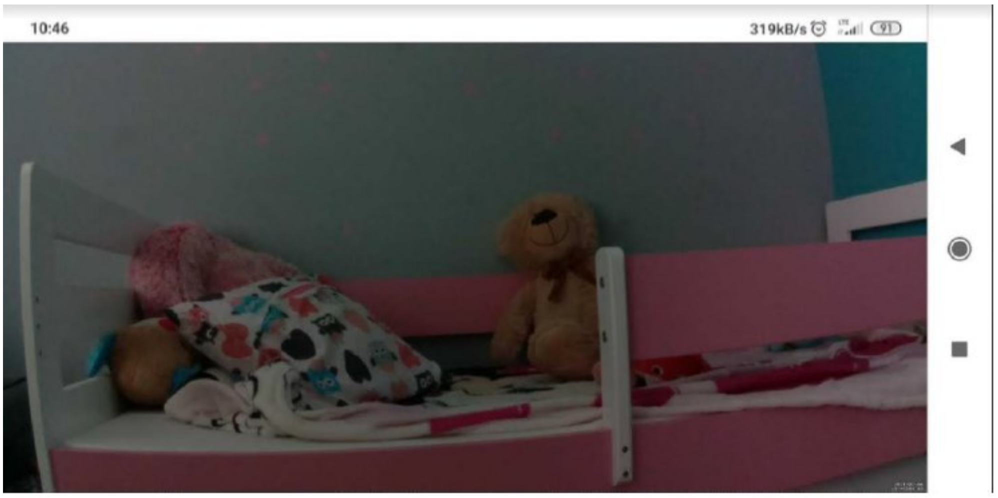

Figure 4. Camera view – day

Figures 4 and 5 present screenshots of the image displayed by the mobile app during day and in darkness imitating nighttime. The illuminators mounted on both sides of the camera ensure a very good visibility and quality during both day and at night. Day and Night viewing modes are switched automatically without the need for user's input.

Figure 5. Camera view – night

After powering-up the system a user receives a text message informing that the system has been turned on. The information regarding switching to emergency power supply has been sent because the AC/DC adapter has been disconnected; the system acted correctly informing a user about switching power supply mode. The system remained in the DAY operating mode and therefore sent an appropriate message after losing a signal from the motion sensor. In order to suspend operations of the system a user sent an appropriate message to the baby monitor system. Due to the fact that informing a user about any possible hazards is a priority the system was able to notify the user one more time before suspending operations. After receiving an appropriate message the system resumed its operations. Figure 6a presents progress of the test.

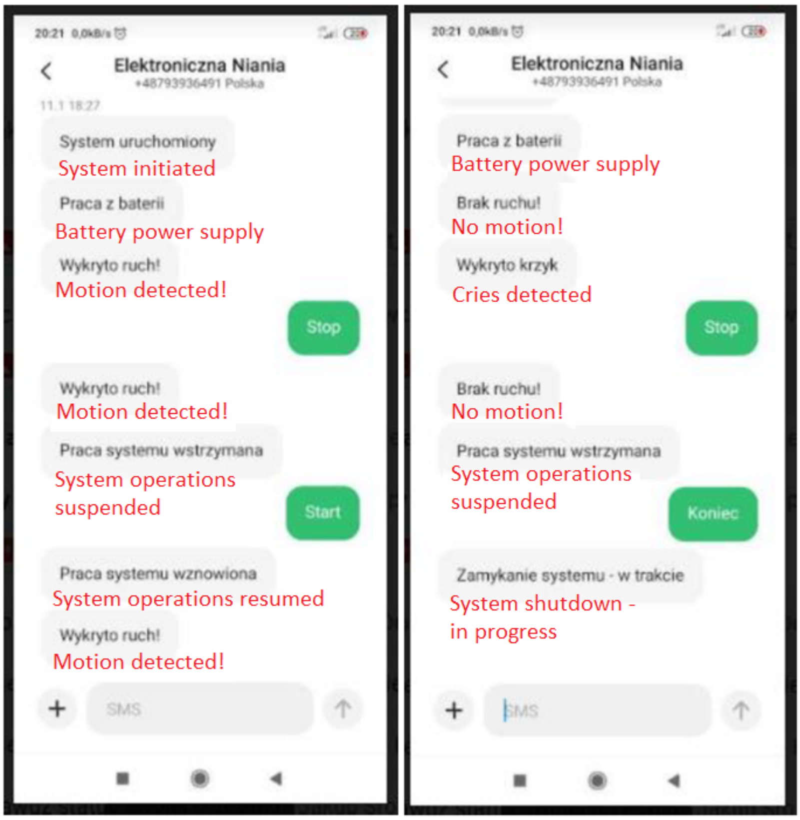

Figure 6. Testing the system part one a) part one, b) part two

The next stage of the system tests covered inspecting operation of the sound sensor and possibility of shutting down the system remotely. After a sound with appropriately high intensity is registered the system sends an appropriate text message. A user is able to shut down the system by sending an appropriate message. In response the system notifies the user that it has initiated the shut-down procedure. The second stage of testing is presented in Figure 6b.

The following tests covered measuring of system's response time to occurring incidents. The time required by the system to reach full operational capacity (from connecting power supply voltage to receiving an SMS confirmation) is approx. 15 s. The time required for suspending operation of the system, counted from a user sending an SMS message to receiving an SMS confirmation sent by the system, is the same. The time required for resuming operations (after suspending work) is shorter and is within the 8-10 seconds range. The complete system shutdown takes 10 seconds and is dependent on availability of the serial port.

Practical operations of the system were tested for 7 consecutive days. In the NIGHT operating mode which lasts approx. 10 hours per day 15 messages regarding detected movement of a child were sent on average. In this mode the system checks state of the motion sensor every 5 seconds. If a child e.g. is restless or rolls over the system detects such motion but such behavior is interpreted by a parent as a false alarm. In the Night mode the system did not signal child's movement for 99.79% of the time. In the Day mode the system checks motion sensor more frequently, every 3 seconds. Such settings resulted in receiving approximately 15 SMS messages per hour of child's sleep on average. Therefore the system operating in the Day mode did not signal movement of a sleeping child for 98.33% of the Day mode duration. The least number of notifications has been generated on the grounds of data from the sound sensor which requires approximately 10-second long signal with an increased intensity to send an SMS message. In practice such signals corresponded with a child waking up and crying for unknown reasons just to fall asleep shortly after. The camera worked correctly for the entire duration of tests (100% of the time).

6. Conclusions

The entire system is controlled by a popular Raspberry Pi 4 microcomputer which issues commands to a GSM module on the basis of the data received from sensors. The software controlling operations of the system has been written in Python programming language dedicated for this popular unit. The remote viewing through a mobile device makes using the system in various conditions easier provided that the Raspberry Pi and the phone remain connected to the same network. Illumiators ensure optimal visibility at nighttime and enable the system to operate around the clock.

Owing to the fact that Raspberry Pi is fitted with an extended GPIO port which can be further expanded by using GPIO input expanders the baby monitor system can become an component of a surveillance system covering the entire premises. Additional cameras with the motion sensing function enabled will ensure safety within the borders of the premises and the motion sensors placed within the house will detect even the slightest movement. The fact that such solution significantly lowers costs of installing a surveillance and alarm systems within a house is also worth mentioning. Uniformity of the system and easy daily operations are another advantage. Instead of using several hubs and a significant amount of wiring security can be ensured by using a single platform the size of a credit card.

The solution presented in this paper displays only a fraction of capabilities of Raspberry Pi 4. An electronic system will ensure safety of a child when guardian performs other work related to day to day life. In an instance of occurrence of an incident deviating from norm the guardian will be notified but the ultimate decision will always lie with the user of the system owing to the fact that no device can be above the safety.

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