Design and Implementation of a Smart Baby Crib

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Abstract. Many people are so busy that they face additional difficulties with everyday life. Parents in particular may have many responsibilities, yet babies and infants continue to need special care. This paper proposes a smart baby crib to help both parents and baby in several ways by providing numerous services in two modes, manual and automatic. In manual mode, the user can control the crib’s swing and start music playing wirelessly using an application installed on a smart phone. In automatic mode, the crib starts swinging automatically when the baby cries, and swings continuously until the baby stops crying alongside playing music to make a baby be quit and sleep. In addition, if the motion and music do not calm the baby, the crib messages the designated parent’s mobile phone using Global System for Mobile communication (GSM) technology to seek immediate attendance. The system is implemented using a microcontroller, a D.C motor, a sound transducer, an h-bridge, and a rechargeable battery, and this has been tested in real time environments. Experimental results show its efficiency and simplicity.

Keywords: Smart system, baby’s crib, GSM, Arduino based smart system.

1. Introduction

Many modern parents may not be able to spend time simply monitoring their babies because of their other responsibilities. However, babies and infant need care and monitoring 24 hours a day. Recently, smart technologies have become widespread in most life fields due to their ability to take automatic actions. Baby care services is a field that could also employ these technologies by means of embedded systems. Embedded systems combine hardware and software to implement a desired function, and, designed correctly, these systems can help parents in terms of baby care and monitoring [1]–[4]. Several studies have been done in this area. The authors in [5] proposed a cradle rocked automatically by an oscillatory action similar to that achieved by an adult rocking a crib with an infant in it, while in [6], an automatic swing cradle powered by a DC motor was designed to swing when the baby cries. The cradle speed in the latter is controlled using a belt system, with a C-channel is used to converts the circular motions into linear motion. In [2], the proposed system enabled the user to control the speed...
of the baby crib. An FN-M16P module was also used to record voice of a parent to be played whenever the baby cried for a long time. Accelerometer and ultrasonic modules were also used to detect the respiratory and non-respiratory movements of the baby. The authors in [7] proposed a system which would swing the cradle based on the baby crying intensity, which utilised cloud computing. The baby’s voice triggered a sensor and a cloud computing network then sent a message to the designated parent; subsequently the cradle was rocked if the parent clicked on the ON button that appeared on the associated web page. Other research has used Arduino microcontrollers with sound sensors to achieve automatic cradle rocking, as in [1] and [8]–[10]. Other researchers have employed IOT facilities with Arduino or Raspberry Pi 3 microcontrollers, such as in [9]–[11], to develop automatic swing actions for babies’ cribs.

This paper proposes a smart system for a baby cradle that combines several services. The proposed system operates in two modes, manual and automatic. The manual mode enables the user of the system to control the cradle rocking speed and to play the baby songs or its parent’s voice by activating an MP3 player. This control is achieved wirelessly using an Android application. In automatic mode, the system operates based on the sound of the baby crying, responding with different speeds over different periods of time. Moreover, the system can also call the parents to demand attendance using GSM technology.

### 2. Modules in the proposed system

The proposed system is designed and implemented based on several new technology modules that are both efficient and low cost. The main modules used in the implemented system are

- **Arduino microcontroller (Type: UNO):** This is an open source platform that provides cheap and simple hardware-software interaction. It can accept analogue and digital signals, process data, and make decisions, acting as a “brain” for several applications that require smart systems. The key features of Arduino-UNO [12] are listed in Table 1.

- **Bluetooth Module (Type: Hc-05):** Bluetooth is a wireless communication method with a maximum data-rate of 1Mb/sec that operates within a range of 100 meters using an indoor frequency of 2.4 GHz. The HC-05 Bluetooth module [13] offers serial communication using internal antennas and in a voltage range of 3.6 – 5 Volts. Its features are described in Table 1.

- **D.C Motor:** This work required a low speed D.C. motor working in the range of 6 to 12 volts. The chosen motor, from the Bringsmart company [14] has high torque and specifications as explained in Table 1.

- **H-Bridge (Type: L298N):** An H-bridge refers to an electronic circuit that switches the load voltage polarity [15]. The L298N is a dual full bridge driver that controls the direction and speed of two individual motors [16]. The key features of L298N are presented in Table 1.

- **GSM/GPRS (Type: SIM900):** The SIM900 is a Quad-band GSM/GPRS solution in a surface mount technology (SMT) module. It is designed with a powerful single-chip processor that integrates an AMR926EJ-S core [17]. The main specifications of GSM/GPRS SIM900 [18] are shown in Table 1.

- **Microphone (Sound Sensor KY-37):** The sensor has three main parts on its circuit board. The first is the sensor unit at the front of the board, which sends an analogue signal to the amplifier. The amplifier then amplifies the received signal according to the value of the potentiometer’s resistance, and then sends the signal to the analogue output of the board. The third segment is a comparator that switches the LED and digital output on where the signal falls below a specific value. The sensitivity of microphone can be controlled by adjusting the potentiometer [20]. The specifications of the used sound sensors are shown in Table 1.

- **Relay (SRD-05VDC-SL-C):** This has three high-voltage terminals, one normally closed (NC) at voltages up to 240 volt, one normally opened (NO) at voltages up to 240 volt, and a common terminal (C), which supplies power to the device to be controlled. The other side of the relay has three low-voltage pins (Ground, VCC (5 volt), and signal) which connect to the Arduino. The Arduino switches the relay On and Off by means of a trigger signal [19].

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[1] [2] [3] [4] [5] [6] [7] [8] [9] [10] [11] [12] [13] [14] [15] [16] [17] [18] [19] [20]
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Table 1. Technical specifications of the electronic modules in the proposed system

| Arduino UNO [12]                          | HC-05 Bluetooth [13]                     |
|-------------------------------------------|-----------------------------------------|
| • Microcontroller type: ATmega328         | • Operating-Voltage: 4V - 6V (Typically 5Volt). |
| • Operating voltage: 5V.                 | • Operating-Current: 30 mA               |
| • Recommended Input Voltage: 7-12V.      | • Range (maximum distance): <100m.      |
| • Boundary of Input Voltage: 5-20V.      | • Works with Serial-communication (USART) and TTL-compatible. |
| • Digital Input/output Pins: 14 Pins (6 pins of them provide PWM output) | • Follows IEEE-802.15.1 standardized protocol. |
| • Analog Input Pins: 6 Pins              | • Uses Frequency Hopping Spread-Spectrum (FHSS). |
| • DC Current per I/O Pin: 40 mA.         | • Operates in Master, Slave or Master/Slave modes. |
| • DC Current for 3.3V Pin: 50 mA.         | • Easily interfaced with Bluetooth of Laptop or Mobile. |
| • Flash Memory: 32 KB of which 0.5 KB used by bootloader. | • Operating Baud rates: 9600,19200,38400,57600,115200,230400,460800 bits/sec. |
| • SRAM: 2 KB (ATmega328)                 |                                         |
| • EEPROM size: 1 KB (ATmega328)          |                                         |
| • Clock Speed (main crystal oscillator): |                                         |
| 16 MHz                                    |                                         |

| 12 Volt D.C Motor [14]                   | H-Bridge L298N [16]                       |
|------------------------------------------|------------------------------------------|
| • Rated-voltage: 6-12V.                  | • Operating voltage up to 46 v.          |
| • No Load Speed: 78 RPM.                 | • Total DC-current up to 4 A.            |
| • Rated-Torque: 55 kgf.cm.               | • Low saturation voltage.                |
| • Reduction-ratio: 1/181.                | • Over-temperature protection.           |
| • Direction: CW&CCW.                     | • Logical “0” input-voltage up to 1.5 V (high noise immunity). |
| • Low noise: dB<45.                      | • Dual full-bridge driver.               |

| GSM/GPRS SIM900[18]                     | Sound Sensor (KY-37) [20]                 |
|------------------------------------------|------------------------------------------|
| • Quad Band 850/ 900/ 1800/ 1900 MHz    | • Operating Voltage: 3.3 to 5 VDC.       |
| • Dual Band 900/ 1900 MHz               | • Frequency Response: 50 Hz - 20 KHz.    |
| • GPRS multiple slot, class 10/8 GPRS mobile-station class-B | • Sensitivity: 48-66 dB                   |
| • Control via AT commands (GSM 07.07 ,07.05 and SIMCOM enhanced AT Commands). | • Impedance: 2.2 kΩ.                      |
| • Low power consumption: 1.5mA(sleep mode) | • It provides a 16-Bit analogue to digital conversion. |
| • Operation-temperature: -40°C up to +85 °C | • Outputs: 1 Pin analogue + 1 Pin Digital. |
|                                          | • Operating temperature: 40°C up to +85 °C. |

3. Proposed smart system for baby crib
The general block diagram for the system is shown Fig. 1, including the Microcontroller (Arduino-UNO), D.C. motor, H-bridge, Bluetooth unit, Global System for Mobile communications (GSM) unit, MP3 player, relay, sound transducer, switch, LEDs, and 12-volt D.C battery.

The proposed system operates in both manual and automatic modes. In manual mode, the system is managed using smartphone input; thus, the user needs to wirelessly communicate with the system. A Bluetooth module is used for this purpose, connected to serial communication pins in the Arduino set to 0 and 1, for receiving and transmitting data respectively. The process of manual control using a smartphone also requires an application operating under the Android operating system. A trusted application from Google play named “Arduino Bluetooth 4CH” was thus employed for this purpose. A user of the system can thus control the operation of the crib swing and MP3 player by accessing this smartphone application and communicating with the system wirelessly through Bluetooth. The user can thus turn the motor on and off and play and stop the Mp3 player.
The system interacts automatically with baby in automatic mode, however. Here, the system senses the baby crying and decides whether to operate the crib swing or not. Furthermore, based on the period of the baby’s crying, it decides whether to play a song or not. If the baby still does not stop crying, the system automatically calls a designated parent to request their attendance on the baby. The algorithms for each mode are thus explained after the components of the proposed system are outlined in more detail.

In order to swing the crib, a motor with low speed and acceptable torque is required. The motor selected has a torque equal to 52 kg.cm and a speed ranging from 20 to 78 RPM. A metal arm is joined to the motor at one side and the other side is joined with a rope connected to the cradle. The speed of the motor is controlled by the H-bridge L298N, which receives instructions from the microcontroller and supplies motor with D.C. voltage taken from a 12 V D.C. battery. The L298N motor controller is a dual motor controller that can easily control the rotation direction of a DC motor, and the H-bridge schematic is shown in Fig 2-a. The direction of motor rotation is dictated by the switches: when S1 and S4 are closed, the left terminal of the motor has a higher voltage than the right terminal, so the motor rotates in one direction. In contrast, when S2 and S3 are closed, the right terminal of the motor has a higher voltage than the left, making the motor rotate in the other direction.

Another important benefit of using an H-bridge is to provide the motor with a separate power supply from the microcontroller, as the latter cannot provide a high enough current. The L298N consists of four input pins corresponding to the four switches, as seen in Fig. 2. As the system has only one motor, the microcontroller is only connected to H-bridge terminals 1 and 2 through pins 5 and 6. Pins 5 and 6 control the motor operation status and direction. In case of both pins having low status (logic 0), the motor is stopped, while if pins 5 and 6 are high and low respectively, the motor rotates in a
forward direction. Reversing the previous case, with pins 5 and 6 low and high, respectively, results in motor rotation in the reverse direction. The L298N driver controls the motor speed through pulse width modulation (PWM) signals provided by two pins in the L298N. In the proposed system, pin 9 from Arduino was chosen for this purpose.

![H-bridge Schematic Diagram](image)

**Figure 2** H-bridge Schematic diagram: (a) equivalent schematic, (b) Status of switches to rotate motor in forward direction, (c) Status of switches to rotate motor in forward direction.

Alongside the motorised swing, an MP3 player is added to the system in order to play lullabies or any other sounds that may help calm the baby. The MP3 player includes an attached SD ram with multiple MP3 files. The turn on and off processes of the MP3 player are controlled by the microcontroller using a relay connected to pin 3.

Two more electronic modules are added to the system to replace manual control. A microphone to sense the baby’s cries is connected to the microcontroller, which decides to operate or stop the swing motor and MP3 according to an algorithm to be explained later. The microphone signal is connected to an analogue pin number A0, with the signal converted to digital using an analogue to digital converter (ADC) within the Arduino with a resolution of 10 bits. The second module is a GSM, used for calling the designated adult if the baby continues to cry during automatic mode. The GSM is connected to Arduino through pins 7 and 8 for receiving and transmission, respectively. The details of the operation steps for both manual and automatic modes are explained in more detail below.

### 3.1 Manual mode algorithm

This mode enables the user of the system to control the system wirelessly using a Bluetooth-linked smartphone app. The operation algorithm steps are shown below:

- **Step 1**: The user turns on the smartphone’s Bluetooth and connects it to the HC-05 module wirelessly using the Android application, as shown in Fig. 3-a.
- **Step 2**: The microcontroller reads the Bluetooth values (BTV) from the serial communication pin for data received at pin 0. Subsequently, it checks the BTV, which is changed according to the application pushbuttons as shown in Fig. 3.
- **Step 3**: If \( BTV = 1 \) (when the user pushes the first pushbutton), pins 5 and 6 are made low and high respectively to rotate the motor in the forward direction; pin 9 is also assigned a number (100) to refer to the low speed (30 rpm); loop to step 2. Otherwise, go to the next step.
- **Step 4**: If \( BTV = 2 \) (when the user pushes the second pushbutton), pins 5 and 6 are made low and high respectively to turn the motor; pin 9 is assigned a number (180) referring to high speed (42 rpm); loop to step 2. Otherwise, go to the next step.
- **Step 5**: If \( BTV = 3 \) (when the user pushes the third pushbutton), then make pin 3 high to close the normally open relay to start the MP3; loop to step 2. Otherwise, go to the next step.
• Step 6: If BTV = 4 (when the user pushes the fourth pushbutton), then make pins 5 and 6 high and low, respectively, to rotate the motor in the reverse direction; pin 9 is assigned a number (100) to refer to the low speed (30 rpm); loop to step 2. Otherwise, go to the next step.

• Step 7: If BTV = A or B or D (when the user pushes off the first, second, or fourth pushbuttons, respectively), then make pins 5 and 6 low to stop the motor, pin 9 is assigned to zero; loop to step 2. Otherwise, go to the next step.

• Step 8: If BTV = C (when the user pushes off the third pushbutton), then make pin 3 low to open the normally open relay in order to stop the MP3; loop to step 2. Otherwise, go to the next step.

• Step 9: If BTV = E (when the user pushes the “ALL on” pushbutton), then make pins 5 and 6 low and high, respectively, and pin 9 is assigned a number (100) to refer to the low speed (30 rpm). Also make pin 3 high to close the normally open relay in order to play the MP3; loop to step 2. Otherwise, go to the next step.

• Step 10: If BTV = F (when the user pushes the “ALL off” pushbutton), then make pins 5 and 6 low to stop the motor; pin 9 is assigned to zero. Also make pin 3 low to open the normally open relay in order to stop the MP3; loop to step 2.

Figure 4 shows a flowchart for this algorithm.

Figure 3 Android application to manage the proposed system in manual mode: (a) Smartphone Bluetooth connection with HC-05, (b) Pushbutton status after Bluetooth connection
Figure 4 Flowchart of the manual mode of the proposed system.
3.2 Automatic mode algorithm

In automatic mode, the proposed system operates without user input. The automatic mode algorithm starts working when the user switches it to automatic mode position, so that the digital input pin 2 is in high status (logic 1). The steps of the algorithm are as follows:

- **Step 1:** The microcontroller reads the microphone values (MV) from analogue pin A0; this value represents the ADC samples with resolutions of 10 bits, with possible values between -512 and 511.

- **Step 2:** The microcontroller continues reading MV for 10 seconds with a delay of 5 milliseconds between samples to get MV frames of 2,000 samples.

- **Step 3:** The microcontroller computes the average value (AV) of the frame MV to use in a simple sound recognition procedure based on comparing the AV value with a threshold (Thr) in order to decide motor rotation. The procedure for sound recognition is not suitable for noisy rooms, though it is suitable for normal quiet rooms and efficient in terms of real time processing.

- **Step 4:** If AV > Thr, make pins 5 and 6 high and low, respectively to rotate the motor in a forward direction. Set pin 9 to (100) to refer to the low speed (30 rpm) and go to the next step. Otherwise return to step 1.

- **Step 5:** Read the MV vector for 60 seconds with a delay of 5 milliseconds between every two samples. Compute AV of MV and check if AV > Thr, then make the motor rotate at speed 2 by writing pin 9 to (180) and go to the next step. Otherwise, make pins 5 and 6 low and write 0 on pin 9 to stop the motor, and return to step 1.

- **Step 6:** Read the MV vector for 30 seconds with a delay of 5 milliseconds between each two samples. Subsequently, compute the AV of MV and check if AV > Thr, then play the MP3 by making pin 3 high and go to the next step. Otherwise, reduce the motor speed to speed 1 by writing (100) on pin 9 and waiting for 30 seconds to stop the motor and MP3; return to step 1.

- **Step 7:** Read the MV vector for 3 minutes with a delay of 5 milliseconds between each two samples. Subsequently, compute the AV of MV and check if AV > Thr, in which case the microcontroller calls the designated adult by sending an SMS using GSM while the motor and MP3 continue running. While computed AV > Thr, repeat step 7. Otherwise, reduce the motor speed to speed 1 by writing (100) on pin 9 and waiting for 60 seconds to stop the motor and MP3; loop to step 1.

Figure 5 shows the flowchart of this algorithm.
Figure 5 Flowchart of the automatic mode of the proposed system.
4. Results and discussion

The parts implemented in the system were individually tested before being combined into a system and connected to a baby’s crib to obtain the final prototype. The manual mode parts were implemented first and the microcontroller programmed to accommodate these. Figure 6 shows the operation of the motor and MP3 individually and together through the smartphone Bluetooth connection. In these tests, the motor was replaced by a relay unit. The same method was used to implement and test the automatic mode parts, based on the sound of the baby’s crying. Where the microphone senses sounds from the environment, the microcontroller analyses the sound period and energy and decides whether to operate the motor or not. The procedure for automatic mode algorithms seen in section 2.2 was also applied in terms of playing the MP3 players, and making calls and sending SMS to the user of the system through GSM. Figure 7 shows the implemented system for automatic mode.

As the tests of individual parts succeeded, the overall system was implemented by combining the parts, with a few changes in programming and hardware. The motor was connected to the H-Bridge and supplied with power by means of an external and chargeable 12 V DC Battery. A simple switch was used for switching between manual and automatic modes. The combined parts as shown in Figure 8 were thus tested in realistic environments for both modes and the crib used contained weight load of up to 12 kg. The proposed sound recognition of automatic system operated properly for quiet and medium noise environments; but it failed for very noisy environments with loud sounds such as the T.V. or people chatting. However, this satisfies the basic requirements, as in automatic mode, the baby can be assumed to be alone in a quiet environment.

![Figure 6 Manual mode parts for testing: (a) The Motor is ON, (b) The MP3 Player is ON, (c) Both the motor and MP3 player are ON, (d) Both the motor and MP3 player are OFF](image-url)
Table 2 shows a comparison for the proposed system and some related works in terms of services provided. The table demonstrates that the proposed crib provides more services than seen in works. Furthermore, it has been implemented and tested in real time usage, while most other works remain without testing.

Table 2 - Comparison of the proposed system with other related works in terms of the provided services

|            | Crib system | Manual swing | Automatic swing | Variable motor speed | MP3-Player | Compatibility with smartphone Apps | GSM communication | Prototype Implementation |
|------------|-------------|--------------|-----------------|----------------------|------------|-------------------------------------|-------------------|--------------------------|
| [2]        | No          | Yes          | Yes             | Yes                  | Yes        | No                                  | Yes               | No                       |
| [5]        | No          | Yes          | No              | No                   | No         | No                                  | Yes               | No                       |
| [6]        | No          | Yes          | Yes             | No                   | No         | No                                  | Yes               | Yes                      |
| [7]        | No          | Yes          | No              | Yes                  | Yes        | No                                  | Yes               | Yes                      |
| Proposed   | Yes         | Yes          | Yes             | Yes                  | Yes        | Yes                                  | Yes               | Yes                      |

In terms of hardware complexity and reliability, [6] and [7] offer more complexity and less reliability compared to the proposed system. In [6], the required electronic circuit board is complex and uses several transformers connected to an electricity supply of 220V in order to provide suitable power supplies for different modules such as the GSM-SIM300 which consumes more than 1 A with a voltage of 12 to 17 volts required for communication. Similarly, in [7], the prototype cannot be utilised realistically, being smaller than an A4 sheet (21 × 29.7) and it implemented in cardboard and weak wood fiber. The hardware in [7] is thus unsuitable for a real baby’s weight and size. In contrast, the mechatronic circuit of the proposed work is low cost and relatively small, yet it has been tested for loads with weights greater than a normal baby weight (10 kg). In addition, all other system components have been tested for real time suitability, and all the devices are supplied from one chargeable 12 Volt battery. This makes the implemented system portable, and it can be carried anywhere as well as operating without an external electricity supply.
In terms of recognition of a baby crying sound, works [2] and [5] to [7] rely on a threshold for a single sample of microphone sensing; where the sample greater than threshold, the motor operates whether the sound is a baby crying or anything else as long as the sample value satisfies the motor operating condition. In contrast, the proposed work records sound for a period of time and utilises the average value of the recorded sound to decide if it is a baby crying sound or not, attaining much higher accuracy.

Figure 8 Parts of the prototype system for the proposed crib: (a) Electronic parts with 12 V battery, (b) Mode switch and sound sensor, (c) D.C. motor, (d) Overall prototype system
5. Conclusions
A smart baby’s crib has been designed and implemented based on several new technologies. The system helps parents during the day while they are busy and during the night while they are sleeping by swinging a cradle and playing a recorded parent’s voice or songs for the baby to keep them quiet. The system operates in two modes, manual and automatic. The user of the system can easily switch between the two modes using a simple switch designed for this purpose. In the manual mode, the system is wirelessly controlled using an Android application installed on a smartphone, which allows input of orders to swing the baby crib and/or play songs or a recorded voice. In the automatic mode, the proposed system senses the sound of the baby crying, subsequently deciding whether to swing the crib and play the MP3-Player based on the time period of the crying session. Furthermore, the system continues to monitor the baby’s crying, altering the swinging of the crib with the desired speed as well as calling the parents if required based on an algorithm explained in section 2.2. The implemented system is very cheap compared to existing cribs, which have fewer services than the proposed system; the total cost of the implemented prototype is less than US$80, and all of the components and modules used in the implemented crib are available in local markets. It is also very simple to use, requiring no special knowledge. The proposed system can be easily developed further to add new services such as sensing moisture and temperature to check if the baby requires a nappy change. It also can be employed in other applications, such as for patient beds, with minor alterations.

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