Sudden Infant Death Syndrome Heart Rate and Temperature Monitor with Audible and Visual Alarms

Jessica Claud, Raymond Carrillo, Justin Wylie, Kevin Jensen, and Tsheilyna Tchang

***Abstract*—The Heart Guardian 9000™ is a heart rate and temperature sensing device, which was constructed for the purpose of preventing cases of Sudden Infant Death Syndrome (SIDS). The device consists of two basic parts, the coordinator, which is meant to stay with the parents for monitoring information and includes an audio speaker and a visual display, and the end device, which is meant to stay with the infant for measuring his or her heart rate and temperature. The product possesses four different alarm settings. A JN5139 Wireless Microcontroller (IEEE802.15.4) serves as the signal processor.**

I. Introduction

THE Heart Guardian 9000™ is a baby monitor that monitors a baby's pulse and temperature to prevent SIDS, or Sudden Infant Death Syndrome. The Heart Guardian 9000™ is wireless and meant to be worn by the baby when the baby is sleeping. The greatest challenge will be being able to directly monitor the baby's vitals, considering his or her small size, and still having the wireless parts communicate with one another.

A. Nomenclature

SIDS is a medical term for the sudden death of an infant that remains unexplained. It is responsible for more deaths than any other cause in childhood for babies of one to six months of age.

II. Technical Work Preparation

The project consists of two main components, the end device and the coordinator. The end device consists of an offspring Jennic 5139 Evaluation Board, a temperature monitoring circuit and a heart rate monitoring circuit. The end device will be attached to the infant. The end device will perform all necessary comparisons to determine whether or not there is an alarm condition. The coordinator will be the monitor unit that is kept with the parents. It consists of the parent Jennic 5139 Evaluation Board, an onboard LCD display, and a speaker circuit. The LCD will display the specific visual alarm being received. The speaker circuit will provide the same audible alarm independent of the type of alarm being received. There are four different alarm settings. The alarm settings for heart rate are heart-rate-too-fast and heart-rate-too-slow. The alarm settings for temperature are temperature-too-high and temperature-too-low. These words will be displayed as the visual alarm on the LCD display.

A. Heart Rate Circuit

Pulse Sensing Circuit
Piezo Film Sensor (film plus electrode)

The heart rate monitoring circuit is part of the end device which is connected to the infant. The direct connection to the infant is via the Piezo Film Sensor. The film is placed firmly against the radial artery on the wrist and secured with tape.

The circuit is driven by a 9 volt source. The circuit draws an exceptionally small amount of current (microamps). This provides very little power consumption by the load and allows the circuit to operate for approximately 3 months utilizing a standard 9 volt battery.

The film sensor senses the vibrations caused by a pulse and sends these signals to five gain stages and circuit filters as shown in the circuit drawing of Figure 1.

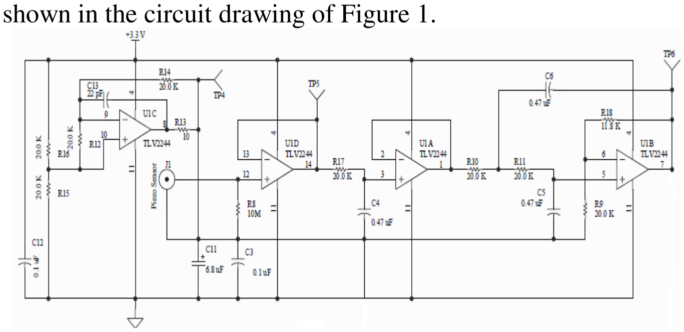

Figure 1: Heart rate pulse sensing circuit

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The circuit provides an amplitude of 2.4 V for a normal adult at rest. The filters in the circuit are used to remove any ambient noise associated with the movement of the film caused by the infant. The output of the circuit provides a pulse signal as shown in Figure 2.

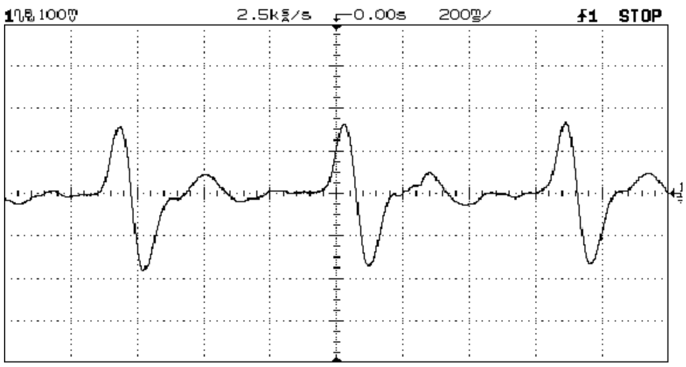

Figure 2: Wrist pulse sample (using Piezo Film Sensor)

A comparator is used to turn the signal shown in Figure 2 into a square wave digital signal which can be used by the Jennic offspring board via the onboard digital input-output (DIO) pins.

B. Temperature Circuit

Temperature Sensing Circuit
Omega ON-400 Temperature Probe

The temperature monitoring circuit is part of the end device which is connected to the infant. The direct connection to the infant is via the Omega ON-400 Temperature Probe. The probe is a banjo type specifically designed to measure sensitive changes in skin temperature. The probe contact is placed under the infant's armpit. The contact is placed firmly against the skin and secured with a piece of tape.

The probe is placed in series with a 1 kΩ resistor and driven by a 1.9 volt source as shown in Figure 3.

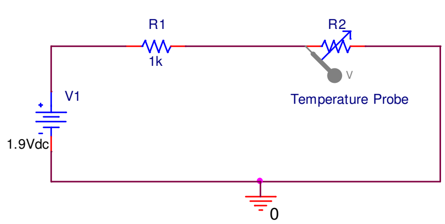

Figure 3: Temperature circuit schematic

The output of the circuit is taken off of the 1 kΩ resistor. A change in temperature will cause a change in the resistance of the probe. This will cause a change in the voltage dropped across both the resistor and the probe. The three conditions, temperature normal, temperature too high, and temperature too low provide specific changes in probe resistance and circuit current. These values are shown in Tables 2 and 3, respectively.

CONDITION	PROBE RESISTANCE (Ω)
TOO LOW	3974
NORMAL	1410
TOO HIGH	1136

Table 2: Probe resistance

CONDITION	CIRCUIT CURRENT (μA)
TOO LOW	380
NORMAL	780
TOO HIGH	880

Table 3: Circuit current

The conditions also provide specific changes in the voltages dropped across the 1 kΩ resistor and the temperature probe. These values are shown in Tables 4 and 5, respectively.

CONDITION	RESISTOR VOLTAGE (V)
TOO LOW	0.38
NORMAL	0.78
TOO HIGH	0.88

Table 4: Resistor voltages

CONDITION	PROBE VOLTAGE (V)
TOO LOW	1.2
NORMAL	1.08
TOO HIGH	0.97

Table 5: Probe voltages

The output from the temperature probe is connected to the onboard analog to digital converter (ADC) pin 4 on the Jennic Offspring Board

C. Jennic 5139 Evaluation Kit

Jennic Coordinator Board (Parent)
Jennic End Device Board (Offspring)
JN5139 Wireless Microcontroller (contained on both Parent and Offspring)

A JN5139 Wireless Microcontroller (IEEE802.15.4) with a 2.4 GHz transceiver will be utilized as the signal processor. The microcontroller will have to be maintained at a temperature within the range of -40° to +85° C.

The temperature circuit is hardwired to the End Device Board via DIO Pin #34 (ADC1), which corresponds to Pin #39 on the JN5139 Microcontroller. The incoming signal will be compared to the board's internal voltage reference of

1.2V (0xfff). The corresponding hexadecimal values for the conditions being tested are shown in Table 6.

CONDITION	PROBE VOLTAGE (V)	HEX VALUE
TOO LOW	1.2	0xfff
NORMAL	1.08	0xdfff
TOO HIGH	0.97	0xcfff

Table 6: Hex values for each probe voltage as sensed by the ADC

If one of these conditions exists, a signal will be sent to the Coordinator Board using the RF module on the End Device Board. The onboard LCD display will be utilized for all visual alarms. DIO Pin #32 on the Coordinator Board, which corresponds to Pin #2 on the JN5139 Microcontroller, acts as the DAC output which will be hardwired to an external speaker circuit as shown in Figure 4.

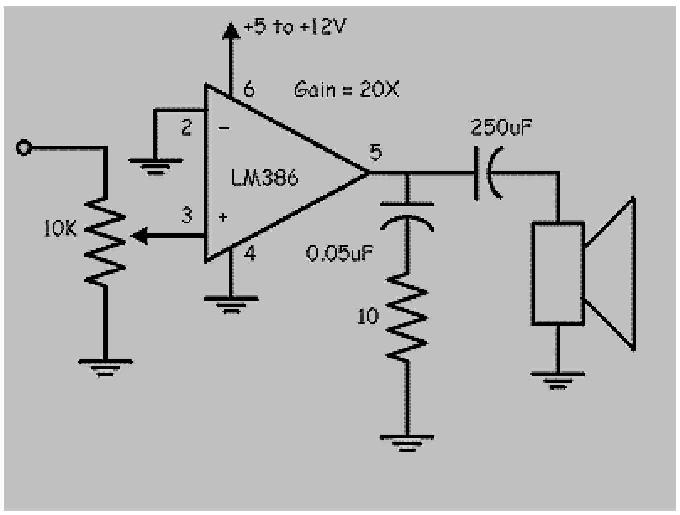

Figure 4: External speaker circuit

The heart rate circuit will be directly hardwired to the End Device Board via DIO Pin #16, which corresponds to Pin #32 on the JN5139 Microcontroller, is configured as a digital input. Every rising edge sensed will be captured, and the time of occurrence will be held. The program will interrupt at the next rising edge. The time of this second rising edge will be captured and held. The difference between the two times is then calculated and stored. The average heart rate at 3 kHz will provide approximately 3 rising edges per second. After one minute, the program will average the differences between sequential rising edges. The three conditions, heart rate normal, heart rate too fast, and heart rate too slow provide specific averages as shown in Table 1.

HEART RATE (BPM)	AVERAGE	CONDITION
85-90	0.67 SEC BETWEEN 2 REs	NORMAL
80	0.75 SEC BETWEEN 2 REs	HR TOO SLOW
100	0.6 SEC BETWEEN 2 REs	HR TOO FAST

Table 7: Timed averages and conditions for adult heart rate settings tested.

If the incoming signal provides an average of less than 0.6 seconds or greater than 0.75 seconds between rising edges and alarm condition is met and a signal will be sent to the Jennic parent board via the onboard RF antenna to cause a visual and audible alarm to occur. The visual alarm will be dependent on the type of alarm received and the audible alarm will independent of the type of alarm received.

D. *Testing*

In order to test for the specific temperature alarm settings, Cold water from a water fountain was used for the "TOO LOW" alarm setting (1.2V across the temperature probe), and hot water heated in a beaker on a hot plate was used for the "TOO HIGH" setting (.97V across the temperature probe). The "NORMAL" setting (1.1V across the temperature probe) was determined by placing the probe in contact with human skin at room temperature.

The heart rate alarm settings were set to 80 beats per minute ("TOO SLOW"), 85 beats per minute ("NORMAL"), and 90 beats per minute ("TOO FAST"). These values were chosen because they were the easiest to test within the confines of our testing atmosphere. The "NORMAL" setting was tested first by sampling the resting heart rates of three test subjects. To test the "TOO FAST" setting, the three tests subjects were asked to run for one minute. After one minute, the heart rate of each subject was tested. Once the test subject's heart rate returned to a normal rate (shown by testing the subject again to ensure "NORMAL"), the "TOO SLOW" setting was tested. This was done by asking the test subject to hold his breath for 30 seconds. After 30 seconds, the heart rate of each subject was tested.

E. *Results*

The results of the test determined that the programs of the Coordinator Board and End Device Board were running properly and in accordance with the purpose of the project. All circuitry and the LCD Display operated properly to display the appropriate alarms for each setting.

III. Conclusion

The Piezo sensor is small enough to fit on a baby and its paper thin dimensions are barely noticeable. Using the Jennic 5139 boards allows easy wireless communication between the baby monitors. The C++ programs calculate and determine whether there is any reason to be alarmed.

This prototype has the Piezo sensor still connected to a larger circuit board. Before production, future research and development in completely wireless sensors that are still small enough for the baby's wrist will be necessary.

The Heart Guardian 9000™ is expected to prevent SIDS by watching an infant's pulse and temperature, and alarming the parents through audio and visual alarms when the vitals are in unhealthy ranges. This can also alert the parents to other complications besides SIDS, such as a fever. Therefore, it would be optimal for every household with an infant to have a Heart Guardian 9000™.

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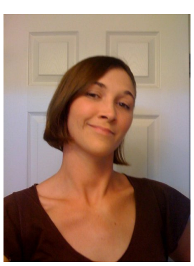
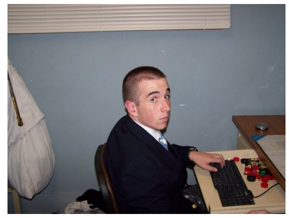
V. Biographies



Jessica Claud is in the U.S. Navy. She is proficient in programming and in hardware. She has been the lead in the team's public affairs. She is a mother of a young son, thus, has a vested interest in the baby monitor project. She will graduate from The Citadel in May 2010 and be commissioned as a U.S. Naval officer.

Ray Carrillo is in the U.S. Navy. He has been working on the circuits of the baby monitors as well as reviewing the monitors' codes. A father, Carrillo sees a great importance in the baby monitor. Carrillo will graduate from The Citadel in May 2010 and continue his career as a commissioned U.S. Naval officer.



Justin Wylie is an undergraduate student at The Citadel. He has been developing the hardware portion of the baby monitor as well as maintaining much of the status updates. Wylie will be taking his Electrical Engineering knowledge into the U.S. Air Force as a commissioned officer after his undergraduate graduation in May 2010.

Kevin Jensen is an undergraduate student at The Citadel. He has helped in the hardware development as well as the program development of the project. Jensen will be a commissioned officer in the U.S. Navy upon graduation in May 2010.

Tsheilyna Tchang is an undergraduate student at The Citadel. She has helped with the circuits in the baby monitors and with the presentation of the project. Tchang plans to continue her education in graduate school after receiving her B.S. in Electrical Engineering in May 2010.