Sleep-state controlled HVAC System

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1. Abstract

It is a common experience that while in sleep state we feel unusually cold sometimes. This causes interrupted sleep and at times even disturbed sleep. This phenomenon is more pronounced for people which conditions like wheezing and other breathing problems. This experience is more common in colder countries where almost every home has a temperature regulation system. Through this project, I intend to address this problem simplistically. This project intends to read a person's sleep state and depending upon that, changes the ambient temperature to ensure sound and undisturbed sleep.

2. Introduction

The project was simulated on LabView. The whole simulation can be divided into two main parts

- The Front Dashboard(Fig. 1.1)
- The internal circuitry and the Function blocks. (Fig.2.1)

These can be further divided as discussed later in this document.

Both these parts are shown in images 1.1 and 1.2

2.1 Project Idea

The project intends to read the physical state of a person, whether the person is awake, exercising, or sleeping, and depending on the waking state of the person changes the ambient temperature of the HVAC system. The sleep state of a person is established by reading the rate of the person's heartbeat. It is medically accepted that the resting heart-rate of a person can be established by studying the heartbeat data of a person over 24-hours. The resting heart rate of a person is the most common heart-rate found by estimating the mode of the heart-rate data. Using the resting heart rate as the yardstick a person's physical state (i.e.) whether the person is sitting, walking, exercising or sleeping can be estimated. The heart rate of a person during sleep state is on an average 80% of their resting state heart-rate. Using this principle we can establish a person's sleep state.

2.2 Project Inspiration

It is often observed that we experience a sudden drop in temperature mid-sleep and feel sudden chills. This is often followed by disturbed sleep, getting up to find a blanket and in a few cases with a history of the phenomenon, increased bet wetting.

This happens because the human body experiences an increased metabolism during the early hours of the day. The Human Body's metabolism peaks at around 3 A.M. This increased metabolism is associated with an increase in body temperature. Due to the increased body temperature, there is an increased heat loss from the body, ergo the person feels colder and at extremes even chills.

3. System Model

As briefed earlier the system can be divided into two:

- The Front Dashboard
- The Internal circuitry.

3.1 The front Dashboard

As shown in image 1.1 the front dashboard consists of a few displays, regulators, monitors, etc. The list, description, and function of all the components are as below:-

- **Heart-rate Waveform Display** – This unit is a modified CRO that shows the waveform of the heartrate in the form of a square-wave. This block serves no

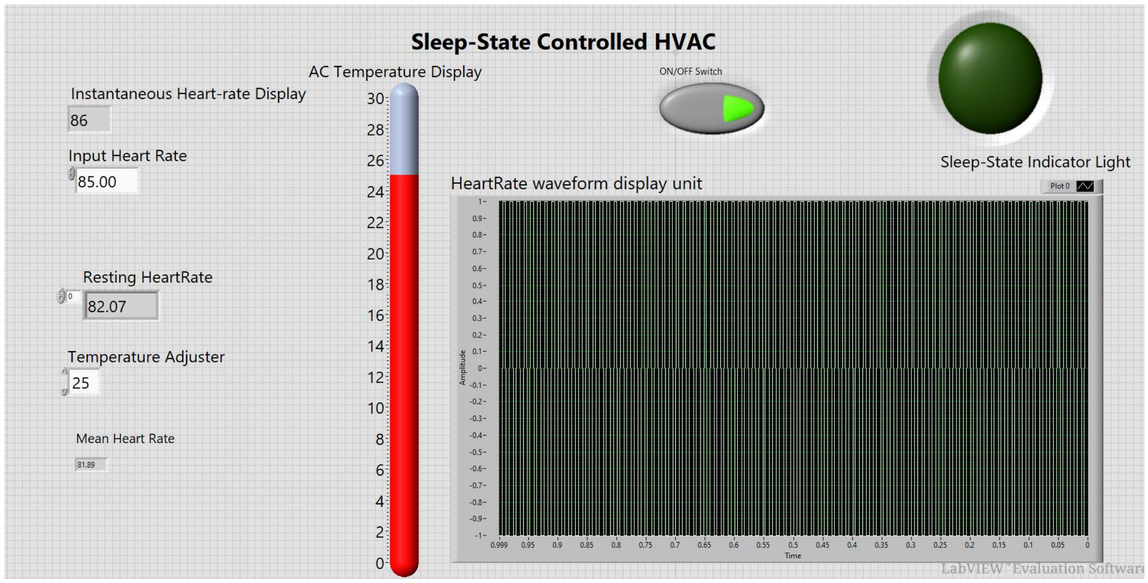

Fig. 1.1 The dashboard of the Sleep-state controlled HVAC System

Functional purpose but is just to display the graphical form of the Heart-rate.

- **Sleep state indication light** – This is an on/off light that serves as an indication of whether the user is in a sleep-state. If the system shows that the person is in a sleep state the light turns ON.

- **AC temperature indicator** – This is a graphical representation of the temperature that the HVAC maintains the room at. When the system recognizes that the person is in a sleep state, we see an increase of 3 degree Celsius (This value can be changed according to user preference).

- **Boolean Switch** – A simple ON/OFF switch to turn the system on and off.

- **There are the following displays that display instantaneous data**:

    - **Instantaneous Heart Rate display –**This monitor shows the instantaneous heart rate of the user. This data is updated every 20 seconds.

    - **Resting Heart-rate –** This is the benchmark heart-rate against which the user's instantaneous heart rate is measured to establish the sleep state. This value is calculated from the data consisting of instantaneous Heart-rate collected over a 24 hour period of time. This data is recorded every 3 minutes over 24 hours.

    - **Mean Heart-Rate –** This displays the mean of the historical heart-rate data. This is the same data that is used to calculate the resting Heart-rate. This figure does not hold any significant value in this project and neither is it used functionally in any block of the simulation. This just shows the user the average heart-rate.

- **The following are the blocks where the Simulation takes input from-**

    - **Instantaneous Heart rate –** Since this is a simulation and

the project needs to be controlled for demonstration purposes, this block takes the input from the user and feeds it to the heart-beat waveform generator.
Note – This bock exists only in the simulation and would not exist in a physical model. In the physical model, a smartwatch would feed the system the instantaneous Heart-beat.

- **Temperature Adjuster** – Through this the user sets the desired temperature. This is equivalent to the generally seen Thermostat common in Households.
  Note – This block will be replaced by the thermostat in the physical model.

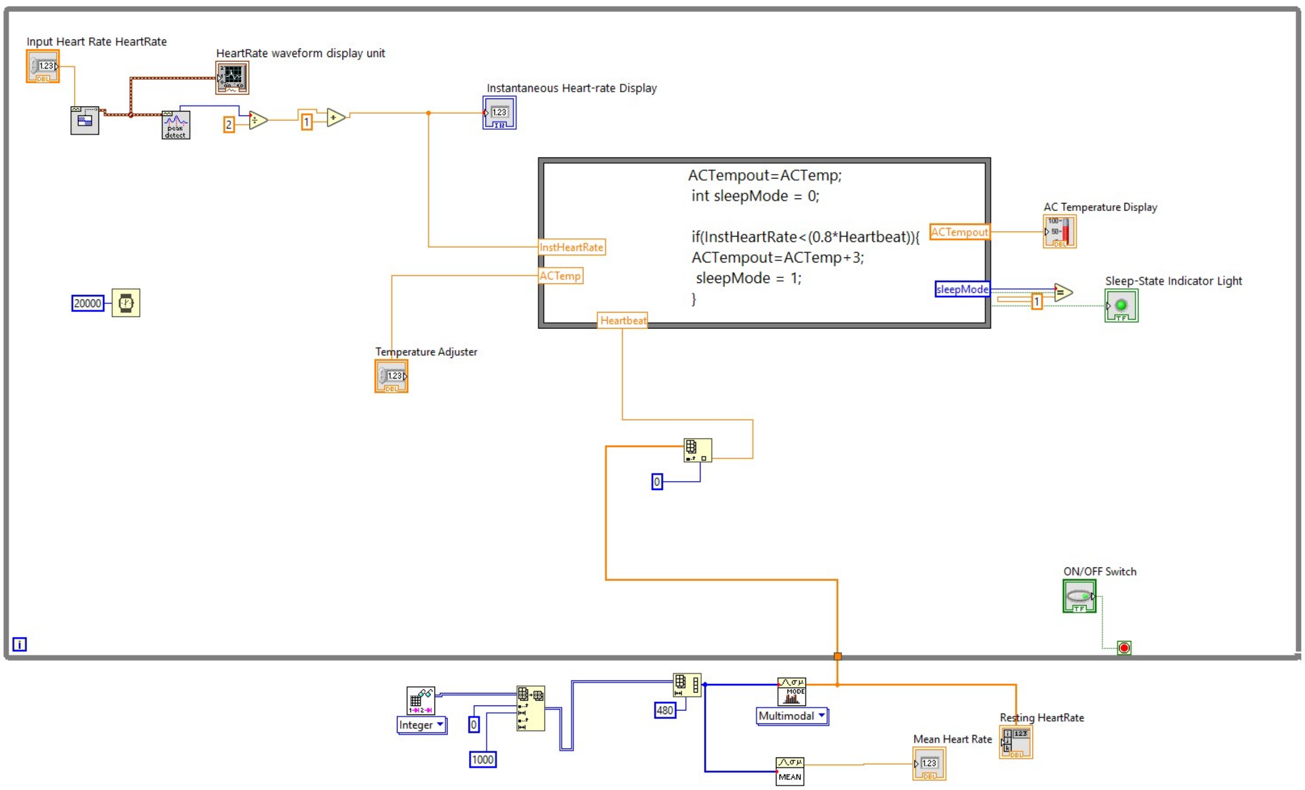

Fig. 1.2 The internal circuitry and the Function blocks.

3.2 The Internal circuitry and the Function blocks.

As shown in Fig. 1.2, the internal circuitry consists mainly of three main blocks:

- Heartbeat Generator.
- Resting Heart-rate Calculator.
- Logic Block.

3.2.1 Heartbeat Generator

Fig 2.1 shows the Section of the internal circuitry that generates the heart beat. This heart beat generation happens over four blocks, one input and two displays are connected to it, for the user to read and understand the data. We shall go over the individual blocks in the following sections.

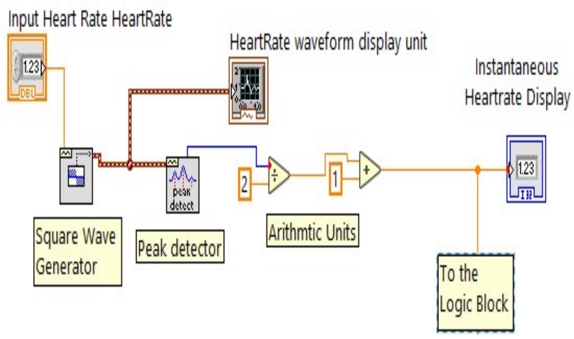

Fig 2.1 Heartbeat Generator

3.2.1.1. The Individual blocks are as follows:

- **Input Heart Rate** – This is the value we use to input the desired heart-rate in the dashboard. This unit is the interface between the Dashboard and the internal circuitry. This block feeds the desired heart-rate in the integer format to the next block.
- **Square wave Generator** – This block simulates the actual smart-watch output, though the heartbeat wave is far from the square wave the smartwatch reads every beat of the pulse as a square wave where the systolic phase is read as a digital high and the rest is read as a digital low, hence giving rise to a square wave. This block feeds the square wave to the Peak Detector Unit and the Heartbeat waveform unit (Explained under Section 3.2.1.2).
- **Peak Detector** – This block detects the peak from the heartbeat and converts the heartbeat into heart-rate. This block outputs an integer value to the next arithmetic units.
- **Arithmetic Units** – The heart rate thus obtained is not perfect; the peak detector outputs the value of the sum of peaks and valleys. Thus this value has to be divided by two to get the value of the number of peaks. The next block adds 1 to this value as the first and the last peaks are together taken as two peaks by the peak detector. This block provides the correction factor to the heart-rate. The output of this is fed to The logic block and a display (Explained under Section 3.2.1.2).

3.2.1.2. The Output units:

- **Heartbeat waveform Display Unit**- This unit outputs the waveform to the **Instantaneous Heart Rate display** (Explained under section 3.1). The block takes the waveform from the square-wave generator block.
- **Instantaneous Heart-rate Display** – This unit is the interface between the Heartbeat generator unit and the Instantaneous Heart-rate display unit on the dashboard.
- **Block Output** – The output of the whole block is the instantaneous heart rate. This is fed to the logic block in the form of integers.

3.2.2 Resting Heart-rate Calculator

Fig 2.2 shows the block diagram of the resting heart-rate calculator. The resting heart-rate of a person can be established by recognizing the most frequent heart-rate of a person over a period of 24 hours. An Excel Sheet with the Heart-rate of a person recorded over 24 hours with an interval of 3 minutes is fed in as an input to this block and the mode of the data is the output of this block.

The various blocks that are employed to enable this conversion are as below:

- **Read Spreadsheet** – This block converts the spreadsheet into an n x n matrix. All the data is limited only to the first column rearrangement of the data is done by the subsequent blocks.

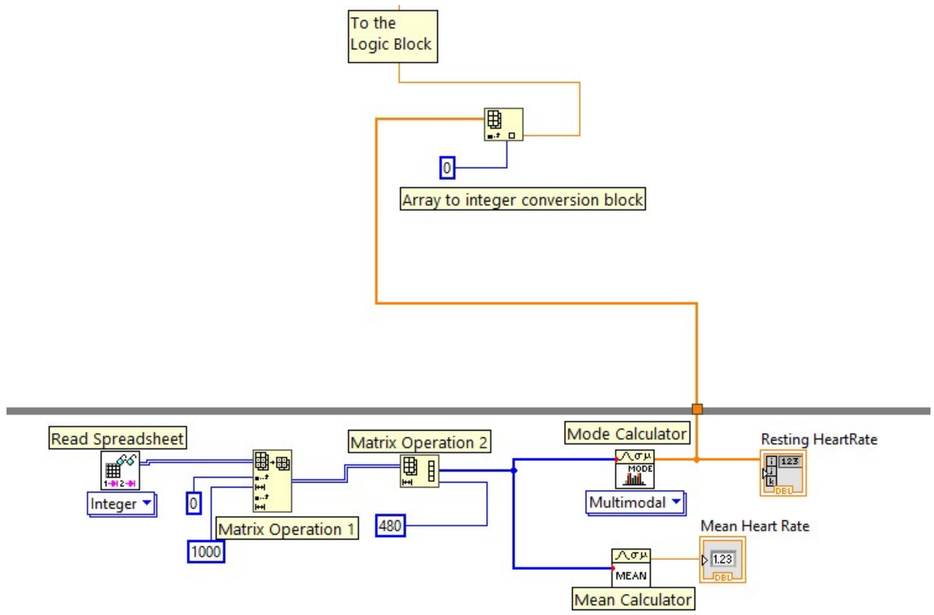

Fig. 2.2 Resting Heart-rate Calculator

- **Matrix Operation Block 1** – As mentioned earlier all the required data is limited to the first column of the matrix. Thus this block is used to convert the n x n matrix into a 1000 x 1 matrix. The value 1000 is an arbitrary value that should be more than the number of recorded observations. The input to this block is the Matrix supplied by the **Read Spreadsheet** block; the other two inputs are the column number (In this case 0) and the number of rows in the column (In this case 1000). The output of this block is a 1000 x 1 matrix with the heart-rate value recorded every 3 minutes over a 24-hour interval.
- **Matrix operation Block 2** – This block receives the column matrix as the input and changes it into a row matrix. This is required to make the data compatible with the mode calculator block.
- **Mode Calculator** – The resting heart-rate of a person can be established by recognizing the most frequent heart-rate of a person over a period of 24 hours. This value is given by the mode of the collected data. The output of this block is thus an array with the mode value.
- **Array to Integer Conversion Block** – The logic block is designed to take in the integer input but since the output of the Mode calculator block is an array, the array to integer conversion block converts the information in the array into Integer format. This integer output of the calculated Resting Heart Rate is fed to the Logic Block.
- **Mean Calculator** – This is an auxiliary block to calculate the mean heart-rate of the user. This doesn't hold any significant function in the Project but it acts as a tool to measure a person's average heart-rate over the last 24 hours.

Output Display Blocks

The Resting Heart-Rate Calculator block outputs the Resting Heart-rate and the mean Heart-Rate through the respective output blocks. These output blocks are the interface between the **Resting Heart-rate Calculator** and the **Resting Heart-rate** display and the **Mean Heart-Rate** display on the Dashboard (Refer Section 3.1).

3.2.3 Logic Block

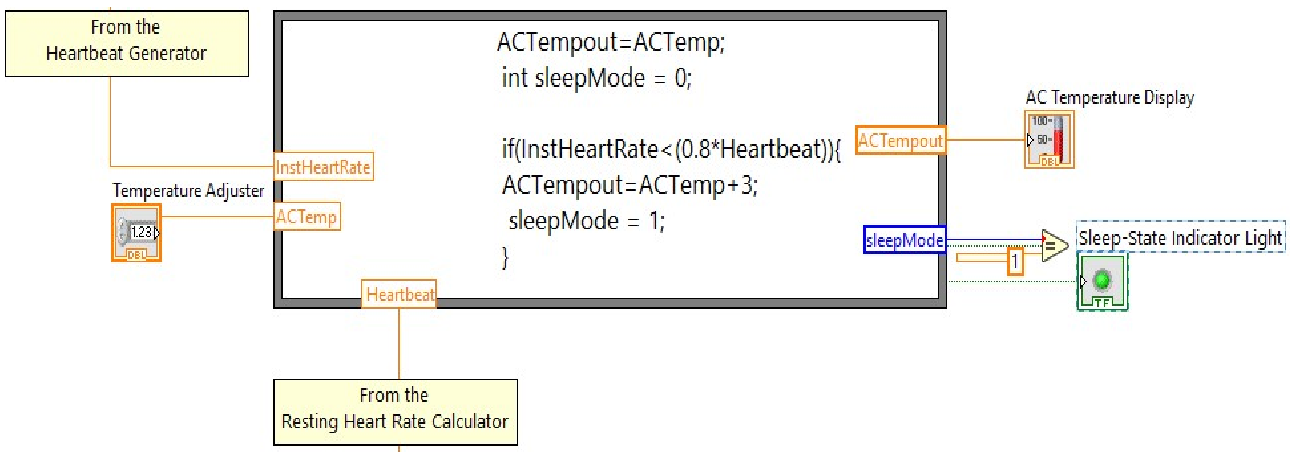

Fig 2.3 Logic Block

Figure 2.3 shows the logic block. The analysis of the logic block can be divided into three parts:

- Inputs.
- Logic.
- Output.

3.2.3.1 Inputs

There are three inputs fed to the Logical Block.

- ***InstHeartRate*** – This is given by the Heartbeat Generator (Section 3.2.1)
- ***Heartbeat*** – This is given by the Resting Heart-rate Calculator (Section 3.2.2)
- ***ACTemp*** – This is given by the Temperature Adjuster. The required temperature is adjusted by the user through the dashboard (Section 3.1). This block is the interface between the dashboard and the Logic Unit. This block inputs the desired ambient temperature.

3.2.3.1 Outputs

The logic block has two outputs

- **ACTempout –** This is the output that changes the temperature of the HVAC system when the user is in sleep state. This essentially is the point of the whole project. The condition for which the output changes is explained in a later section.
- **SleepMode –** This is a flag output to show whether the system is in sleep mode or not. When the system is in Sleep Mode the output is 1, else it is 0. This output is fed to a comparator, the output of which is connected to the Sleep State indicator light on the Dashboard (Section 3.1). Thus through this output, we can know whether the system is in Sleep State.

3.2.3.3 Logic

The following is the code that is at the heart of the whole project and the Logic Block.

```
ACTempout=ACTemp;
int sleepMode = 0;
if(InstHeartRate<(0.8*Heartbeat))
{
   ACTempout=ACTemp+3;
   sleepMode = 1;
}
```

In essence, the code establishes if the instantaneous heart-beat is less than 80% of the Resting Heart-rate.

- If the condition is true then the TempOut (The output) will be increased by 3 degree Celsius.

- If the condition is False, then the temperature is not changed. ACTempout is the same as the input ACTemp.

3.2.3.1 Miscellaneous Blocks

Additionally to the main blocks that are as explained above, there are a few blocks that ensure smooth working of the whole simulation. They are as follows:

- Timer block – This timer block has been set to 20 seconds and this triggers the WHILE loop. The blocks that are included in the WHILE loop are:
  - Logic Block (Section 3.2.3).
  - Heartbeat Generator (Section 3.2.1)
- Boolean Switch – This is essentially a switch to turn the whole system ON and OFF.

4. Results

The simulation was run successfully and the stability, responsiveness of the system was tested at various input values of Temperature and Instantaneous Heart rate.

5. Conclusion

Based on the available data, to avoid disturbed sleep we can manipulate the room temperature to make it more pleasant and conducive based on heartbeat monitoring. This simulation demonstrates how we can manipulate the temperature based off of heartbeat of a person and maintains the ambient temperature to provide uninterrupted restful sleep.

6. Scope for Improvement

1. This project can further be enhanced and be more effective by also monitoring the sleep states of dreams. If there are disturbances observed, the temperature and other physical parameters can be manipulated to improve the person's sleep.
2. This project can be implemented to study the sleep state of more than one person and control the climate depending on who is sleeping.
3. This project with slight modification can be used to personalize room temperatures by recognizing the person in the room through heartbeat profiling.
4. The project can be broadened to check the outside climate condition, estimate the physical sate of the person and control the climate based on that. (eg. When a person has come home after an exercise session and the weather outside is hot, the person desires extra cooling.)
5. A subsystem can be added to inform the authorities of an emergency health situation if the heart-rate shows some chronic conditions like a heart attack, epilepsy, or a stroke.

7. References

1. Sleep and Metabolism: An Overview (2010)
Sunil Sharma * and Mani Kavuru.

2. A Review of Wrist-Worn Wearable: Sensors, Models, and Challenges. (2008)
Rasha M. Al-Eidan,[1] Hend Al-Khalifa,[1] and Abdul Malik Al-Salman[1], [1]College of Computer and Information Sciences, King Saud University, Riyadh, Saudi Arabia

3. Heart Rate during Sleep: Implications for Monitoring Training Status. (2003)
Miriam R. Waldeck* and Michael I. Lambert

4. A Sleep Analysis Method Based on Heart Rate Variability (2019)
Firstbeat Technologies Oy

7. Relevant Links

YouTube -https://youtu.be/rQ3miZkrTQA
GitHub - https://github.com/ruthvikps/Sleep-Stae-Contorlled-HVAC-system.git