

Design and Implementation of a Patient Monitoring and Environmental Safety System using LabVIEW

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Project Report

A comprehensive simulation of physiological signal processing and environmental control logic using National Instruments LabVIEW.

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1 Abstract

This project details the design and implementation of a dual-purpose instrumentation system using National Instruments LabVIEW. The system is divided into two primary modules:

1. **Biomedical Monitoring:** Simulates and analyzes critical physiological parameters including Electrocardiogram (ECG) Heart Rate, Galvanic Skin Response (GSR), Body Temperature, and Metabolic Rate (BMI/BMR).
2. **Environmental Safety:** Monitors ambient room conditions, controls HVAC systems via a closed-loop controller, and manages fire suppression using a Finite State Machine (FSM).

The integration of these modules creates a holistic hospital ward simulation that ensures both patient health monitoring and physical safety.

2 Theoretical Background & Equations

2.1 Body Mass Index (BMI)

BMI is a static measure of body fat based on height and weight:

$$BMI = \frac{\text{Weight (kg)}}{(\text{Height (m)})^2}$$

Note: Height entered in cm is automatically converted to meters inside LabVIEW.

2.2 Basal Metabolic Rate (BMR)

The system uses the **Mifflin-St Jeor Equation**. A Case Structure handles gender-based formula selection.

Male:

$$BMR = (10W) + (6.25H) - (5 \cdot Age) + 5$$

Female:

$$BMR = (10W) + (6.25H) - (5 \cdot Age) - 161$$

2.3 Heart Rate Calculation

Heart Rate is computed from the signal's dominant frequency:

$$BPM = (\text{Frequency (Hz)}) \times 20$$

3 Module 1: Patient Monitoring System

3.1 User Interface (Front Panel)

The Dashboard is designed to resemble a commercial patient monitor. The left panel handles static anthropometric data (Height, Weight, Gender), while the center displays real-time waveforms. The right panel contains the safety controls and status indicators.

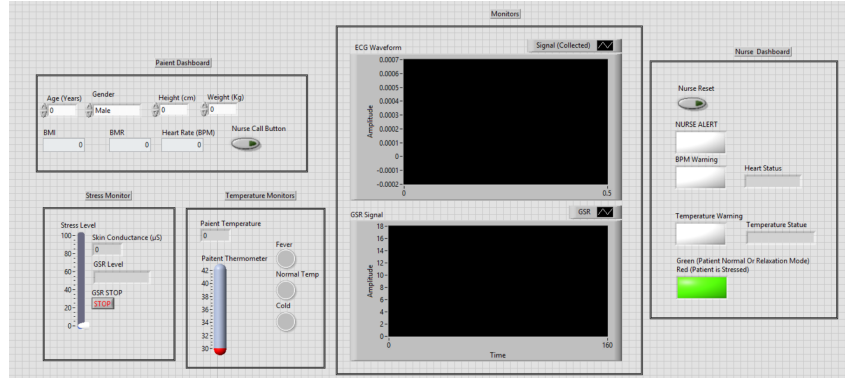


Figure 1: Main Patient Monitoring Interface displaying ECG, GSR, and vital statistics.

3.2 Metabolic Calculator (BMR and BMI)

This sub-routine processes the user inputs. As seen in the block diagram, the height input is divided by 100 to convert centimeters to meters before being squared for the BMI calculation. The BMR logic uses a Case Structure to apply the gender-specific offset (+5 for males, -161 for females).

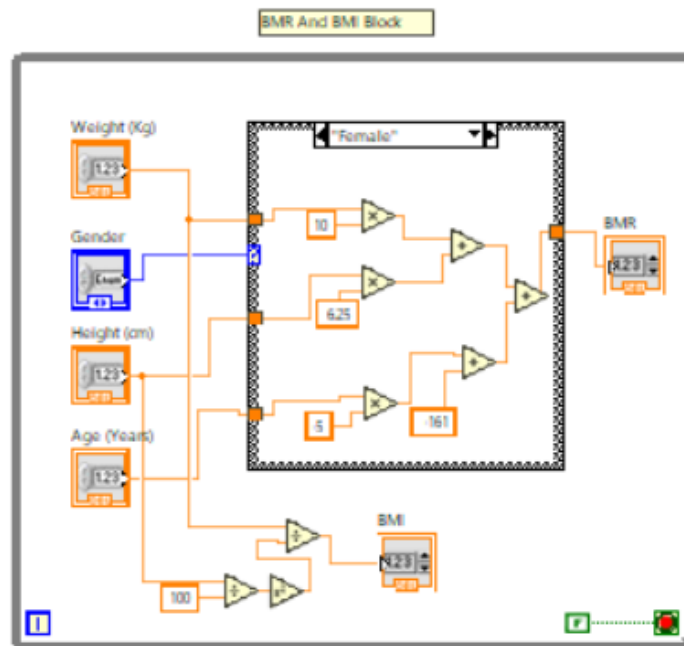


Figure 2: BMR and BMI calculation block.

3.3 Galvanic Skin Response (GSR) Simulation

The Galvanic Skin Response (GSR) module is implemented as a **fully software-based physiological simulation** without any physical electrodes or sensors. Since real skin conductance cannot be measured in this environment, a **Stress Level Control** slider is introduced to emulate sympathetic nervous system activity.

Physiologically, an increase in stress leads to higher sweat gland activity, which reduces skin resistance and increases skin conductance. This behavior is mathematically modeled inside LabVIEW.

3.3.1 Signal Modeling

The simulated GSR signal consists of three components:

- **Baseline Component:** A low-frequency sine wave representing tonic skin conductance.
- **Stress Component:** A scaled contribution derived directly from the Stress Level Control.
- **Noise Component:** A low-amplitude random signal representing physiological and electronic noise.

$$GSR(t) = G_{\text{base}}(t) + k \cdot S + n(t)$$

where S represents the stress level and k is a proportional gain constant.

3.3.2 Signal Conditioning

A low-pass Butterworth filter (cutoff frequency ≈ 1 Hz) is applied to remove high-frequency noise while preserving slow physiological variations.

3.3.3 Stress Classification

The mean value of the filtered GSR signal is continuously calculated and compared against predefined thresholds using a Case Structure. Based on this comparison, the subject's state is classified into:

- Relaxed
- Normal
- High Stress

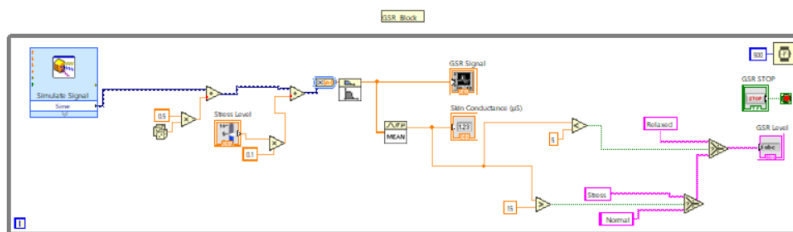


Figure 3: Software-based GSR simulation using Stress Level Control.

3.4 Stress-Dependent Body Temperature

In this project, body temperature is not modeled as a purely random or static variable. Instead, a more realistic physiological behavior is achieved by incorporating the effect of psychological stress, as indicated by the Galvanic Skin Response (GSR) system.

3.4.1 Temperature Input and Base Value

The primary temperature input is obtained from a simulated patient thermometer control. This value represents the baseline body temperature under normal resting conditions. The thermometer signal is continuously updated inside a While Loop to emulate real-time monitoring.

3.4.2 Effect of Stress Level on Body Temperature

Clinical studies show that elevated psychological stress may lead to a slight increase in body temperature due to increased metabolic activity and sympathetic nervous system activation. To reflect this behavior, the stress level is integrated into the temperature calculation.

A Case Structure is used to determine whether the stress contribution should be applied:

- **True Case (High Stress):** When the stress level exceeds the predefined threshold, a small temperature increment is added to the baseline value.
- **False Case (Normal / Relaxed):** When stress is low, the baseline temperature is passed without modification.

Mathematically, the temperature model can be expressed as:

$$T_{\text{body}} = \begin{cases} T_{\text{base}} + \alpha \cdot S, & \text{if stress is high} \\ T_{\text{base}}, & \text{otherwise} \end{cases}$$

where:

- T_{base} is the thermometer reading,
- S is the stress level,
- α is a proportional gain controlling the effect of stress on temperature.

3.4.3 Temperature Classification Logic

The computed body temperature is continuously compared against clinically accepted thresholds using comparison blocks. Based on the comparison results, the patient thermal condition is classified into three states:

- **Cold:** $T < 36^{\circ}\text{C}$
- **Normal Temperature:** $36^{\circ}\text{C} \leq T \leq 38^{\circ}\text{C}$
- **Fever:** $T > 38^{\circ}\text{C}$

Each state activates a corresponding LED indicator on the front panel, providing immediate visual feedback to medical staff.

3.4.4 Temperature Warning Signal

In addition to visual indicators, a **Temperature Warning** boolean signal is generated whenever the temperature is classified as either *Cold* or *Fever*. This warning signal is routed to the Nurse Calling System, allowing abnormal temperature conditions to automatically trigger medical alerts.

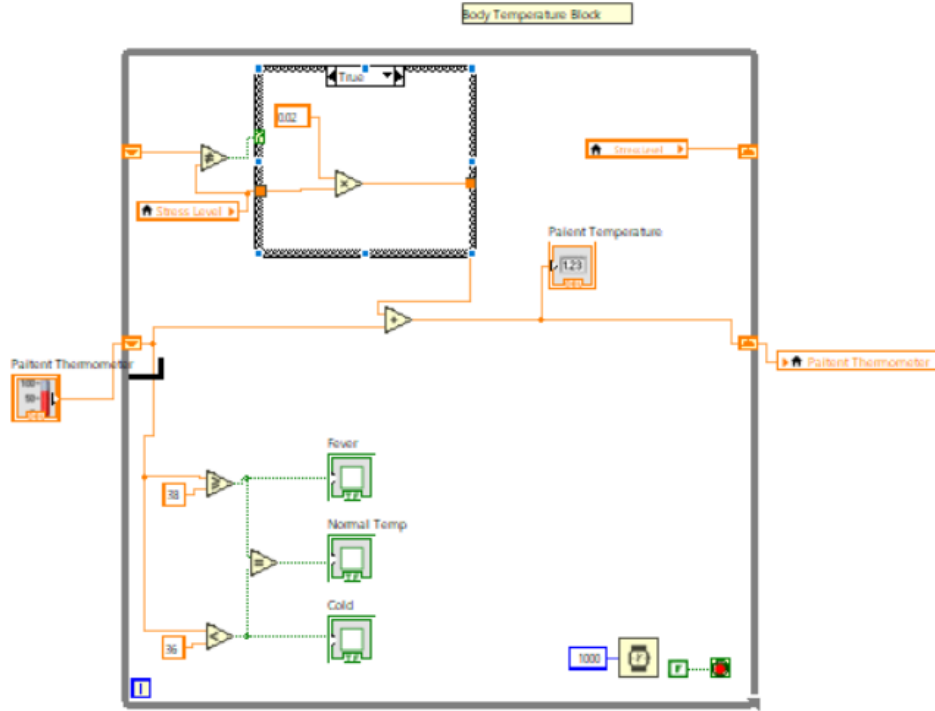


Figure 4: Body temperature simulation with stress-dependent logic and classification indicators.

3.5 ECG Signal Generation and Heart Rate Processing

The Electrocardiogram (ECG) subsystem is responsible for simulating cardiac electrical activity and extracting the patient's heart rate in real time. Since no physical electrodes are used, the ECG waveform is generated programmatically to emulate a realistic cardiac signal suitable for signal processing and safety logic validation.

3.5.1 ECG Waveform Simulation

The ECG signal is generated as a periodic waveform that represents the electrical depolarization and repolarization cycles of the heart. The simulated waveform includes:

- A dominant fundamental frequency corresponding to the heart rate.
- Harmonic components that improve waveform realism.
- Low-amplitude random noise to emulate measurement and physiological disturbances.

The generated ECG waveform is continuously updated within a While Loop, enabling real-time monitoring and processing.

3.5.2 Frequency-Domain Heart Rate Extraction

To extract the heart rate, the ECG signal is processed using the **Tone Measurements Express VI**. This block performs frequency-domain analysis to identify the dominant frequency component of the ECG waveform.

The detected fundamental frequency f (in Hz) is converted to heart rate in Beats Per Minute (BPM) using the following relationship:

$$BPM = f \times 20$$

This conversion factor is selected to match the internal scaling of the simulated ECG signal and provides a stable BPM estimation.

3.5.3 Heart Rate Classification

The calculated BPM value is compared against predefined clinical thresholds using comparison blocks. Based on these comparisons, the heart rate is classified into one of the following states:

- **Bradycardia:** BPM below the lower safe limit.
- **Normal Heart Rate:** BPM within the acceptable range.
- **Tachycardia:** BPM above the upper safe limit.

Corresponding LED indicators are activated on the front panel to provide immediate visual feedback.

3.5.4 Abnormal Heart Rate Warning Signal

Whenever the heart rate is classified as either bradycardia or tachycardia, an **Abnormal Heart Rate** boolean warning signal is asserted. This signal is routed directly to the Nurse Calling System, allowing cardiac abnormalities to automatically trigger a medical alert.

3.5.5 Noise Immunity and System Robustness

To improve robustness, the heart rate decision logic relies on the extracted dominant frequency rather than instantaneous time-domain peaks. This approach reduces sensitivity to noise, transient spikes, and minor waveform distortions, resulting in more reliable alarm behavior.

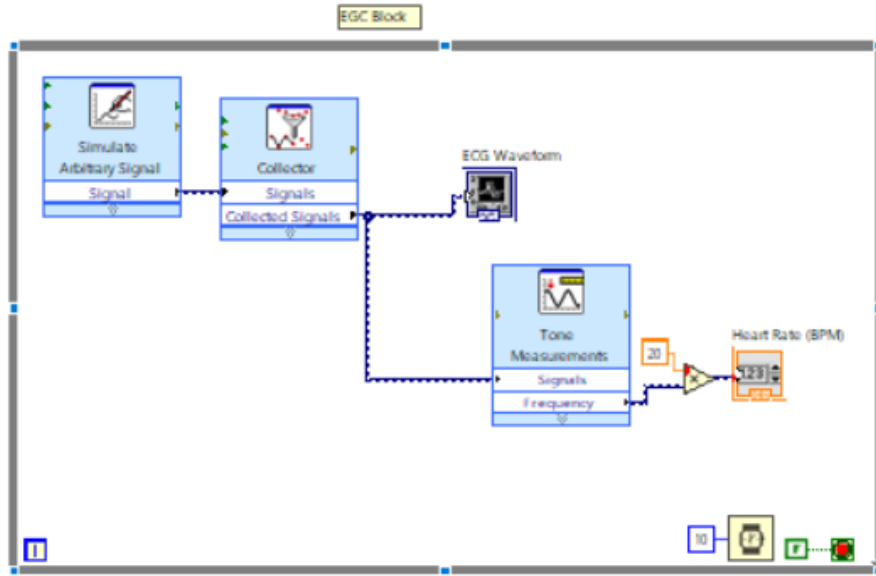


Figure 5: ECG waveform simulation and heart rate extraction using Tone Measurements.

3.6 Nurse Calling System

The Nurse Calling System represents the primary patient safety mechanism in the monitoring module. It is designed to ensure that any critical physiological or psychological condition results in a persistent alert that requires direct medical acknowledgment.

3.6.1 System Architecture

The system is implemented using a **Set-Reset (SR) latch** configuration. This structure guarantees alarm persistence, meaning that once an alarm is triggered, it remains active until manually cleared by nursing staff. This behavior is essential in medical environments to prevent missed or transient alerts.

3.6.2 Alarm Trigger Conditions

The **Set** input of the SR latch is driven by the output of an OR gate that aggregates multiple independent alarm sources. The alarm is activated if **any** of the following conditions become true:

1. **Manual Nurse Call Button:** Allows the patient to directly request medical assistance.

2. **Abnormal Body Temperature:** Triggered when the temperature is classified as either fever or hypothermia.
3. **Abnormal Heart Rate:** Activated during tachycardia or bradycardia conditions.
4. **Psychological Stress Condition (GSR-Based):** Triggered when the GSR value exceeds the predefined stress threshold.

3.6.3 GSR-Based Stress Logic Integration

The Galvanic Skin Response (GSR) signal is continuously monitored and compared against a threshold value of 15 using a comparator block. The output of this comparison is used in two parallel paths:

- **Stress Detection Path:**
 - If **GSR** > 15 , the patient is classified as stressed.
 - A logical TRUE is generated and routed to the OR gate, enabling automatic nurse call activation.
- **Visual Feedback Path:**
 - **Red LED** is activated when $\text{GSR} > 15$, indicating a high stress state.
 - **Green LED** is activated when $\text{GSR} \leq 15$, indicating a relaxed or normal psychological condition.

This dual-path design ensures that psychological stress contributes both to safety logic and to immediate visual awareness on the front panel.

3.6.4 Latch Reset Mechanism

The **Reset** input of the SR latch is controlled exclusively by a dedicated Nurse Reset button. This ensures that once an alarm is asserted, it cannot be cleared automatically by signal normalization or noise, but only through deliberate medical intervention.

3.6.5 Fail-Safe Behavior

Due to the latch-based architecture, the system exhibits fail-safe behavior:

- Temporary signal drops do not deactivate the alarm.
- Noise-induced fluctuations in GSR or temperature do not reset the system.
- The alarm remains active until explicitly acknowledged.

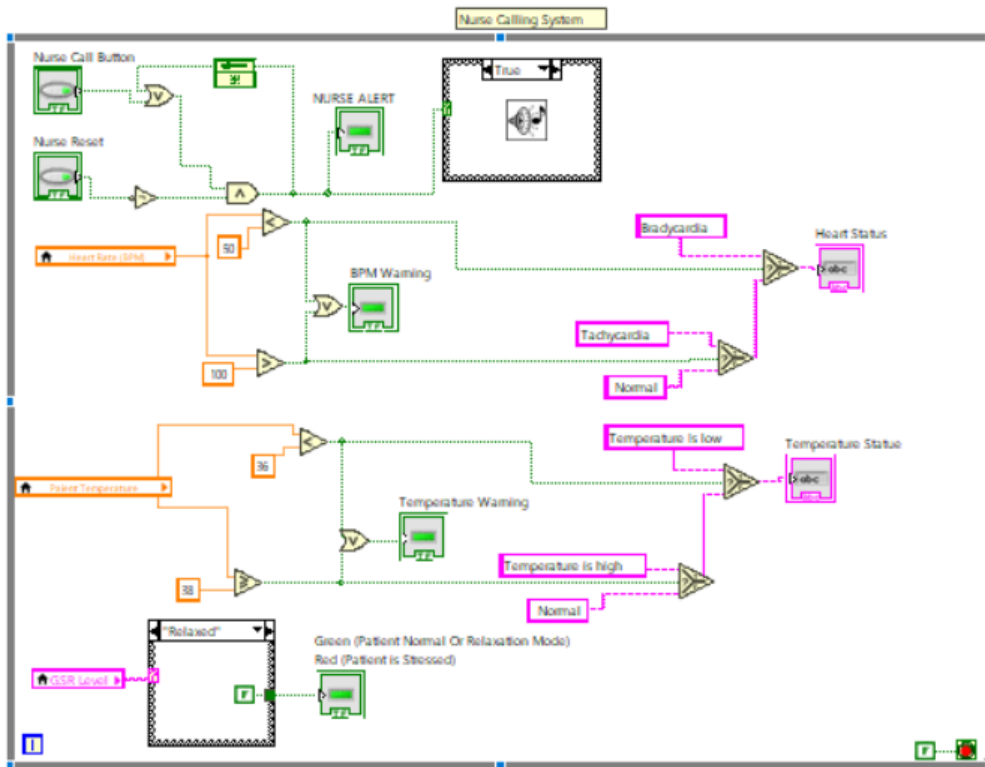


Figure 6: Stress-aware nurse calling system using SR latch logic and multi-condition alarm triggering.

4 Module 2: Firestop System

4.1 Overview of Control Strategy

The proposed firestop system is designed for hospital patient rooms with AC conditioner control system, prioritizing both rapid response and patient safety. The system controls the alarm status, room temperature, and the CO2 fire suppression discharge. The control logic relies on a two-stage verification process:

- **Environmental Detection:** Monitoring smoke and temperature levels against pre-defined setpoints.
- **Safety Interlock:** A manual confirmation ("No One Inside") is required to authorize the release of CO2, preventing potential asphyxiation hazards to patients or staff still in the room.

4.2 Detection and Alarm Activation

The primary detection logic is implemented using two comparison operators. The system accepts analog inputs from smoke detectors and temperature sensors.

- **1st sensor:** The current smoke level is compared to a Smoke Set Point. If the detected level exceeds the threshold, a boolean TRUE signal is generated.
- **2nd sensor:** The current temperature is compared to a Temperature Set Point which is $57^{\circ}C$. If the detected level exceeds the threshold, a boolean TRUE signal is generated.
- **Alarm Output:** As shown in Figure 7, the comparison outputs are fed into an OR gate. Consequently, the general Alarm state becomes active if either the sensors detect a fire.
- **CO2 Valve Control:** The same alarm signal is used as a preliminary condition for CO2 discharge, pending further safety verification with manual button for checking if no one is in the room before discharge.

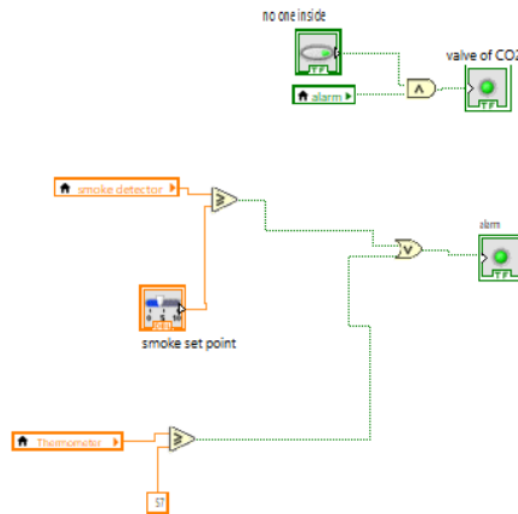


Figure 7: Fire detection logic.

4.2.1 CO2 Discharge Simulation

when CO2 valve is triggered we enter a while loop where to simulate the discharge of CO2 from Tank, we implemented a shift register that stores CO2 tank volume, initialized to full capacity (e.g., 100 units).

Inside the loop, a subtraction function reduces the tank volume by a fixed decrement in each iteration.

the output passes through an In Range and Coerce function, ensuring it does not drop below a certain value.

if the alarm is stopped or the valve of CO2 is closed we exist the loop.

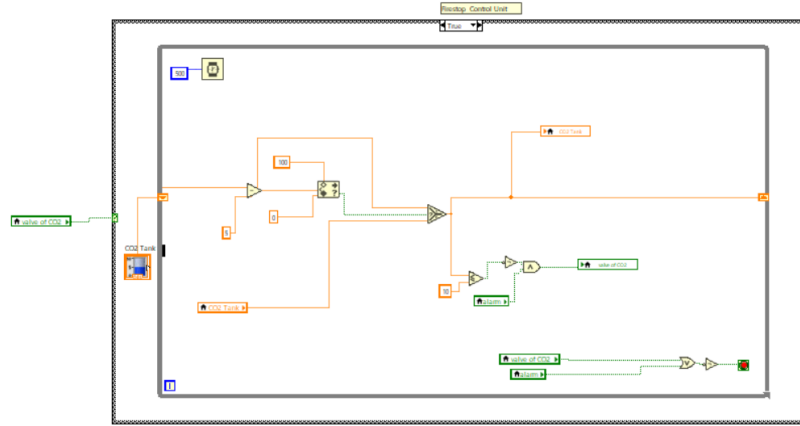


Figure 8: CO2 Discharge Simulation.

4.2.2 Door Locking Mechanism

To enhance safety during fire events, the system incorporates an automatic door locking mechanism: if alarm is activated but there is someone in the room then the door is forced to be opened. but if the alarm is activated and there is no one in the room then the door is locked to prevent entry until the fire hazard is cleared.

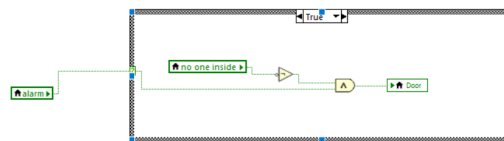


Figure 9: Automatic door locking mechanism during fire events.

4.3 HVAC Control and Temperature Simulation

The HVAC (Heating, Ventilation, and Air Conditioning) subsystem operates on a model-based simulation and does not rely on real-world thermal sensors.

The logic generates a realistic temperature curve based on user inputs and fan speed.

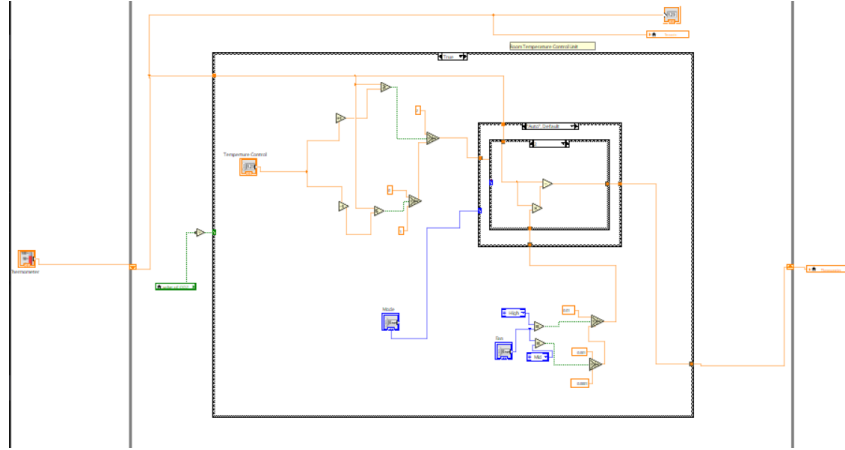


Figure 10: AC control and temperature feedback loop.

4.3.1 Fan Speed & Simulation Rate Logic

To simulate the physical effect of a fan, the rate of temperature change is adjusted according to the selected Fan Mode:

- **High Speed:** Outputs a rate factor of 0.01, representing rapid temperature change (fast cooling/heating).
- **Mid Speed:** Outputs 0.001, representing a moderate rate of change.
- **Low Speed:** Defaults to 0.0001 for very slow passive temperature drift.

Implementation: A nested **Select Function** structure outputs a floating-point constant based on the "Fan" Enum state. These factors are added or subtracted from the current temperature in each simulation iteration, controlling the "thermal inertia" of the room.

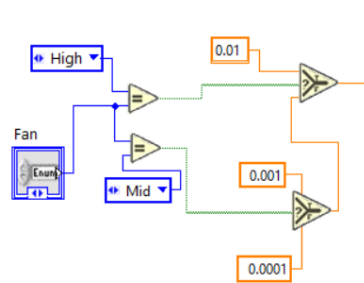


Figure 11: Fan speed selection and temperature feedback control logic.

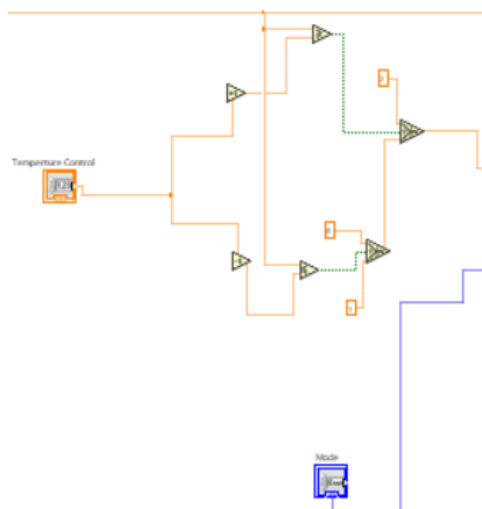
4.3.2 Manual AC Mode

we have three modes for AC control

-
- Figure 1 shows three block diagrams of the control system in different modes. Each diagram is enclosed in a rectangular frame with a dotted border. The input signal enters from the left. In (a) Auto Mode, the signal goes through a block labeled '1' and then to the summing junction. In (b) Cool Mode, the signal splits: one path goes through a block labeled '2' and then to the summing junction, while the other path goes through a block labeled 'x' and then to the summing junction. In (c) Warm Mode, the signal splits: one path goes through a block labeled '0, Default' and then to the summing junction, while the other path goes through a block labeled 'x' and then to the summing junction. The output of the summing junction goes through a block labeled '1' and then to the summing junction. The output of the summing junction is the system output.

4.3.3 Temperature Feedback Loop (The "Auto" Logic)

- **Comparison:** Current Temperature (from feedback node) vs. Desired Temperature (Setpoint).
- **Directional Logic:**
 - If Current < Desired: Add the Rate Factor to the current temperature.
 - If Current > Desired: Subtract the Rate Factor, causing the temperature to drop.
 - If Current a degree less or more: Maintain current temperature (no change).



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4.3.4 Fire Alarm Safety Interlock

A critical safety feature links HVAC operation to the fire detection system:

- **Threshold Monitoring:** The simulated temperature is monitored against a safety threshold (e.g., 50°C).
- **System Override:** If the temperature exceeds this threshold or the main Fire Alarm is triggered:
 - The AC system is forced into OFF state, halting simulated air movement.
 - This prevents circulation of smoke and feeding oxygen to a potential fire, following standard building safety codes.

4.4 Front Panel Design

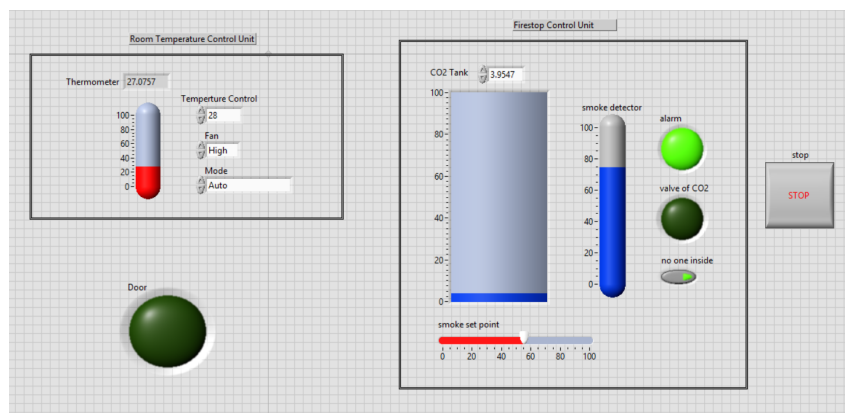


Figure 14: Firestop System Main Dashboard displaying HVAC controls, fire detection status, and CO2 discharge simulation.

5 Conclusion

The integrated patient monitoring and safety system demonstrates the flexibility of LabVIEW in biomedical and industrial automation. By combining physiological signal simulation with state-machine-driven environmental control, the system models a modern hospital ward capable of responding to emergency conditions and maintaining patient safety.

6 References

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