Design and VLSI Implementation of a MIPS-Based Wearable Patient Activity and Cardiac Monitoring System using Accelerometer and PPG Sensor

Review-I

AY 2025-26

GITAM (Deemed-to-be) University

Capstone Project – Introduction (PROJ2999)

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Objective and Goals

Objective

Brief Description

To design and implement a smart wearable system using a MIPS-based processor that monitors patient activity and cardiac health in real time. The system aims to integrate accelerometer and PPG sensors for accurate detection of movement and heart rate, process the data using low-power VLSI architecture, and validate the design on FPGA using Xilinx Vivado. The goal is to create a compact, energy-efficient, and reliable solution for remote health monitoring, elderly care, and emergency alert applications.

Goals

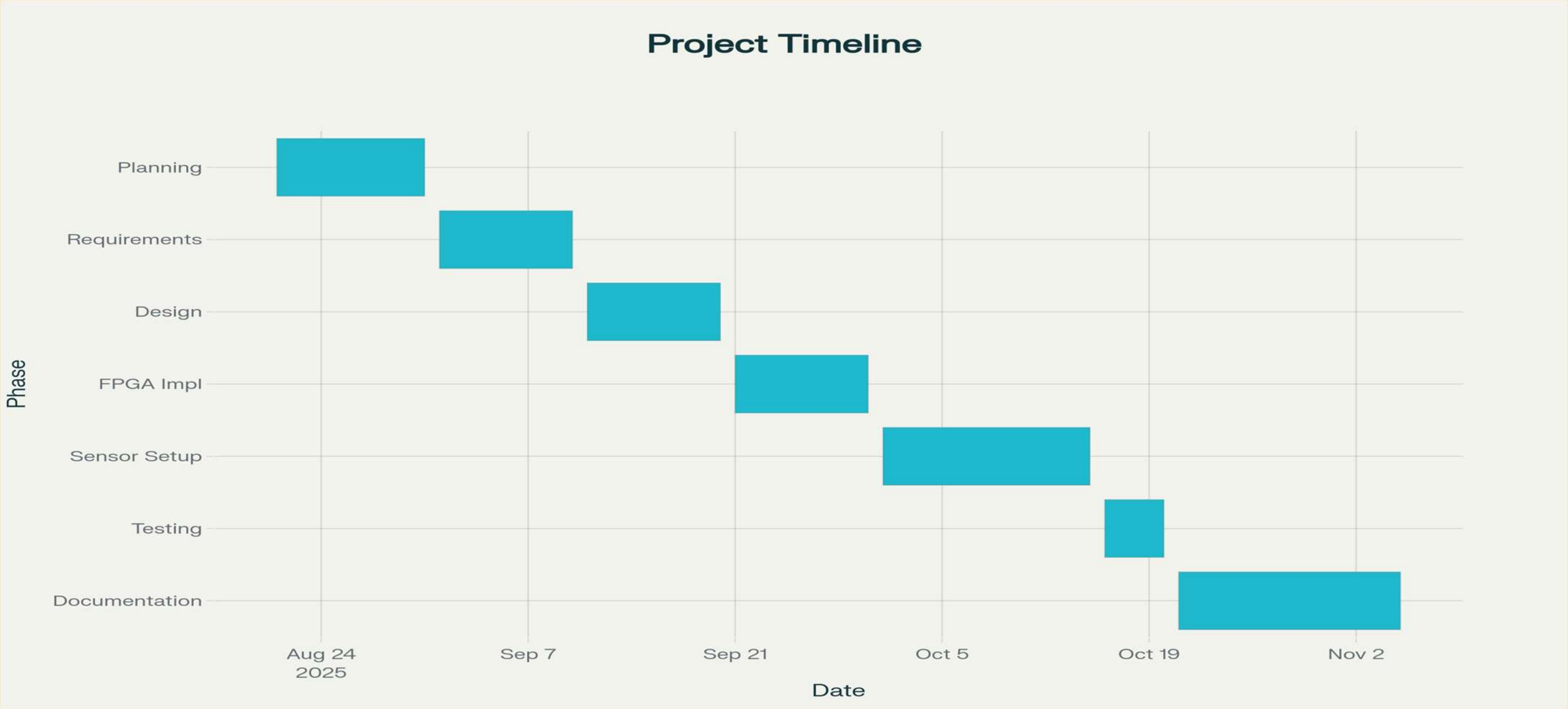
Main Goals

- Design a wearable health monitoring system**-** using accelerometer and PPG sensors for real-time activity and cardiac tracking.
- Implement a MIPS-based processor architecture -to handle sensor data efficiently with low power consumption.
- Develop RTL modules in Xilinx Vivado **-**and validate the design through simulation and synthesis.
- Integrate the system on an FPGA board- to test real-time performance and hardware functionality.
- Ensure compact, energy-efficient VLSI design -suitable for wearable applications in healthcare and fitness.

Additional Goals

- Enable fall detection and abnormal heart rate alerts for emergency response.
- Support wireless communication (e.g., Bluetooth) for remote monitoring and data logging.
- Demonstrate the potential of embedded systems in biomedical applications, combining electronics and healthcare innovation.

Project Plan (Clearly mention milestone for objectives under each reviews)



Literature Survey

Key Publications

- Google scholar research best 6-8 papers

1. "A review on wearable photoplethysmography sensors and their potential for health monitoring" — D. Castaneda et al., 2018.
   Review of PPG fundamentals, signal issues (motion artefact), and algorithms used in wearables. PMC

2. "Wearable devices for ambulatory cardiac monitoring" — F. Sana et al., 2020.
   Survey of ambulatory cardiac-monitoring devices and clinical/engineering challenges for wearable heart-rate/ECG/PPG systems. PMC

3. "Intelligent healthcare enabled by ML and wearable sensors" — S. Chen et al., 2025 (PMC).
   Recent review that covers ML on wearables, sensor fusion (accelerometer + PPG) and FPGA/edge processing possibilities — useful for FPGA+MIPS+algorithm context. PMC

4. "Raw Photoplethysmography as an Enhancement for Physical Activity Assessment" — P.R. Hibbing et al., 2024.
   Discusses using raw PPG (and sensor fusion with accelerometer) for activity contexts — useful when designing motion-robust HR extraction on the MIPS side. PMC

5. "Decoding Human Activities: Analyzing Wearable Accelerometer and Gyroscope Data" — arXiv, 2023.
   Modern methods for feature extraction and activity classification from accelerometer streams — helpful for activity detection algorithms running on MIPS. arXiv

6. "MIPSfpga: using a commercial MIPS soft-core in computer engineering education" — S.L. Harris et al., 2017.
   Practical guide & examples to integrate a MIPS softcore on FPGA including adding peripherals — directly applicable to your MIPS integration plan. IET Research Journal

7. (Implementation paper) "FPGA implementation of PPG and SpO2 sensor/actuator" (Design of an oximeter using FPGA) — Sensors / ResearchGate example.
   Concrete FPGA design examples for LED driving, ADC/PPG capture and digital filtering — useful reference for hardware blocks you'll connect to MIPS. ResearchGate

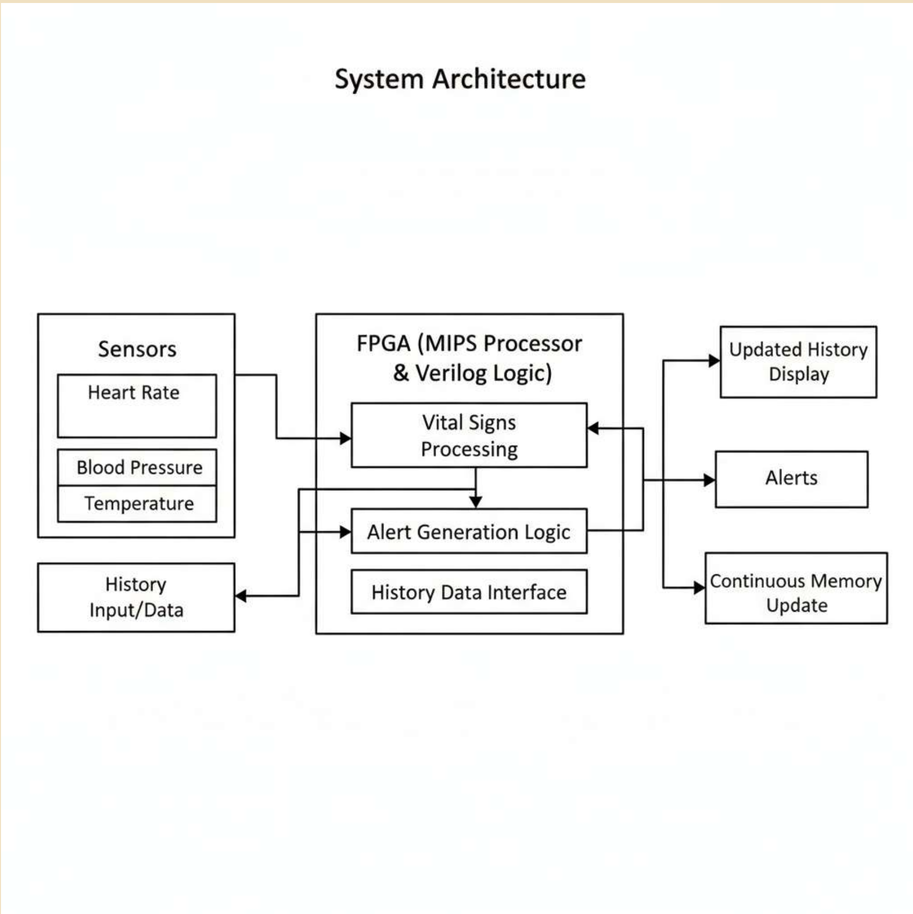
Key resources (whitepapers | app notes | datasheets) — put on one slide

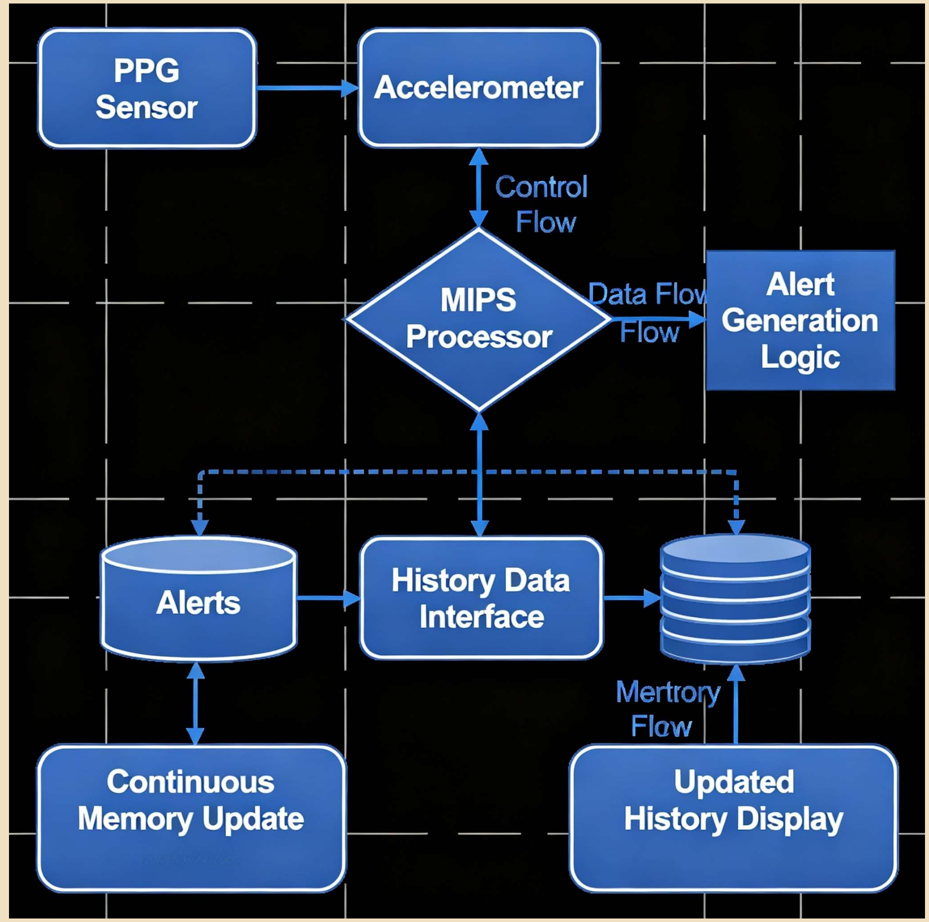
- ADXL345 datasheet (Analog Devices) — for SPI/I²C accel interface, register map, timing. Analog Devices+1
- MAX30100 datasheet (Maxim / Analog Devices) — PPG/SpO_2 sensor registers, timing, LED drive specs. Analog Devices+1
- ADXL345 App Note (AN-1077 Quick Start / self-test) — recommended init & self-test sequences. Analog Devices
- MAX30100 application notes / user guides (vendor examples & driver notes) — for I²C register usage and sample code. AllDatasheet+1
- FPGA + ML on edge whitepapers (examples from 2024–2025 reviews) — choices for where to place filtering vs. feature extraction (FPGA vs MIPS). PMC+1

Existing implementations — Products | Open source | GitHub (one slide)

- GitHub — SPI_Accelerometer (ADXL345) FPGA driver & master SPI HDL — a ready HDL driver you can reuse/adapt for SPI master to read ADXL345. GitHub
- FPGA PPG / oximeter implementations (ResearchGate examples + Sensors paper) — FPGA designs showing LED drivers, sampling, and digital filters for PPG/SpO_2. Good for HDL reference blocks. ResearchGate
- SPI on FPGA tutorial / implementation using LabVIEW / academic PDF — practical SPI implementation patterns for FPGA masters reading accelerometers. ResearchGate
- MIPSfpga educational resources / repos — reference MIPS softcore setups + peripheral integration examples (UART, memory-mapped I/O) to copy for your sensor registers. IET Research Journal

Architecture





Use Cases & Testing

Use Cases

Patient Activity Monitoring

- Detect daily movement patterns (walking, sitting, running) using accelerometer data.

Cardiac Monitoring

- Measure heart rate and SpO_2 levels in real time using the PPG sensor.

Fall / Abnormal Activity Detection

- Identify sudden accelerometer spikes to detect falls or abnormal motion.

Remote Health Insights

- Processed data from MIPS core can be logged/displayed for doctors or caregivers.

Test Cases

Accelerometer Interface Test

- Verify SPI communication with ADXL345.
- Input simulated motion data → confirm correct values on LEDs/7-segment.

PPG Sensor Interface Test

- Verify I^2C communication with MAX30100.
- Check raw heart rate signals displayed via MIPS output.

Integration Test (MIPS Core)

- Ensure MIPS firmware correctly reads sensor registers.
- Validate processed data (activity + HR) against known reference values.

System Reliability Test

- Run continuous monitoring for several hours.
- Confirm no data loss, timing errors, or communication failures.

Implementation and Results – Iteration 1

Implementation – Iteration 1

- Configured FPGA infrastructure: LEDs, switches, push buttons, 7-segment display.
- Implemented clock divider for timing control.
- Mapped digital input signals (switches/buttons) → FPGA outputs (LEDs/7-segment).
- Verified functionality through simulation and on-board testing.

Results – Iteration 1

- FPGA synthesized and programmed successfully with no errors.
- Switches and buttons correctly controlled LEDs and 7-segment display.
- Digital signal flow validated from inputs → FPGA logic → outputs.
- Outcome: FPGA infrastructure is ready for sensor interface integration in Iteration 2.

Implementation and Results – Iteration 2

Implementation – Iteration 2 (Planned)

- Add sensor interface modules:
  - SPI for Accelerometer (ADXL345).
  - I²C for PPG Sensor (MAX30100).
- Modify top_module to include sensor ports (MISO/MOSI/SCLK/CS, SDA/SCL).
- Integrate spi_reader and i2c_controller modules.
- Simulate sensor data using testbench and FPGA switches.
- Display captured values on LEDs/7-segment for verification.

Expected Results – Iteration 2

- FPGA synthesizes and programs without errors.
- Accelerometer mock data captured via SPI and shown on LEDs.
- PPG module handshake verified over I²C.
- End-to-end data flow from sensor interface → FPGA → output display validated.
- Outcome: Sensor interfaces confirmed functional, enabling MIPS integration in Iteration 3.

Implementation and Results – Iteration 3 (Optional)

Implementation – Iteration 3 (Planned)

- Instantiate MIPS softcore processor on FPGA.
- Map SPI (Accelerometer) and I^2C (PPG) sensor data into MIPS memory/registers.
- Develop firmware to:
  - Read accelerometer & PPG sensor data.
  - Process values for activity detection and cardiac monitoring (heart rate).
  - Output processed results to LEDs / 7-segment display.
- Validate integration through test programs on MIPS.

Expected Results – Iteration 3

- MIPS processor successfully reads sensor data via memory-mapped registers.
- Processed activity (motion patterns) and cardiac metrics (heart rate, SpO_2) displayed in real time.
- System runs continuously with no timing errors or data loss.
- Outcome: Fully functional MIPS-based wearable patient activity & cardiac monitoring system

Conclusion & Future Work

Summary and Conclusion

- The project aims to design a MIPS-based wearable patient activity & cardiac monitoring system on FPGA.
- FPGA provides a flexible and reconfigurable platform for integrating digital signal processing and sensor interfaces.
- Proposed system will enable real-time activity tracking (via accelerometer) and cardiac monitoring (via PPG sensor).
- This approach demonstrates the potential of FPGA + MIPS architecture in wearable healthcare devices.

Future Work

- Implement sensor interfacing (SPI/I²C) for accelerometer and PPG sensor.
- Integrate a MIPS softcore processor on FPGA for data acquisition and processing.
- Test and validate system accuracy with real-time sensor data.
- Extend towards IoT-based remote health monitoring solutions.

THANK YOU

Have a Great Day !