

Posture & Neck Strain Monitor for Long Study Sessions

ECE 445 Project Proposal

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1 Introduction

1.1 Problem

Long study or work sessions at a desk make it easy to slip into bad posture without noticing until neck or back pain has already set in. A 2026 study of 507 University of Jordan students found that 52.4% had neck pain in just the prior week, and slouching without back support roughly doubled the odds of it [3]. Laptop and tablet use for studying, which is exactly what we're targeting, was linked to an even bigger jump in neck pain risk than phone use [3]. With more classes and work going remote or hybrid, people are spending more hours than ever hunched over screens, so this problem does not seem like it will go away on its own.

When it comes to existing fixes, they don't really work for everyday use. Desk mounted cameras are expensive and raise obvious privacy concerns, as they're recording video of you and whoever else is in the room. On the opposite end, back braces are bulky and uncomfortable to wear for hours. Additionally, phone apps usually need a subscription and constant phone interaction, and after some feedback from TAs, we found that single IMU clip-on posture trackers have always been unreliable, because one IMU can't tell the difference between actually slouching and just glancing down at a book. We wanted something small, cheap, and standalone that works without needing a phone, a subscription, or a camera pointed at you.

This also isn't just an individual annoyance, as preventable strain like can add up to real healthcare costs and lost productivity, and expensive subscription based trackers put good posture tools out of reach for a lot of people. A cheap and camera free device is something that can actually be shared and used across pretty much any budget or living situation.

1.2 Solution

Our fix is a double IMU wearable, where one IMU sits on the glasses to collect head orientation, and one sits on the collar or shirt to collect torso orientation, connected by a thin wire. Comparing the two gives us the actual angle between the head and the torso, which is a good measure of neck strain compared to trusting one sensor's absolute orientation.

You would start by calibrating a "neutral" posture once, sitting normally, and the device tracks how far you move away from that baseline. If you slouch past a set angle for too long, it vibrates (and lights an LED) to notify you to sit back up. The system breaks into three main pieces: sensing (the two IMUs), processing and control (an STM32 doing sensor fusion and threshold logic), and feedback and power (motor, LED, button, battery). If we have time, we'll add a BLE link so a phone app can log posture trends over time.

1.3 Visual Aid

Figure 1 shows how the device is actually worn and used: the collar unit talks to the glasses IMU over a thin wire, drives the vibration/LED alert, and, as an extra goal, can push data to a phone app over BLE.

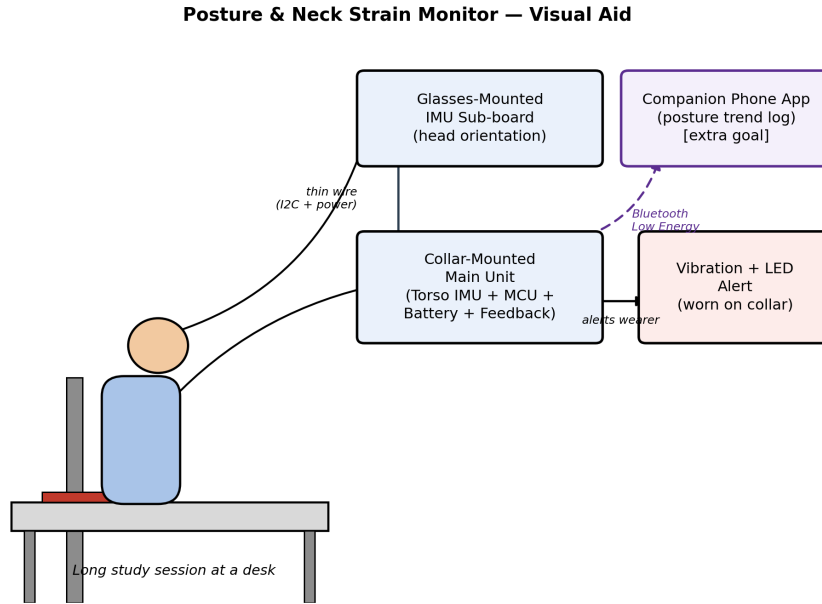


Figure 1: Visual aid: how the device is worn and used during a study session.

1.4 High-Level Requirements

- The device must detect a sustained relative head to torso angle of at least 15° from the calibrated baseline and alert within 1 second of that deviation lasting 10 seconds, hitting at least a 90% detection rate across trials that include head only and torso only movement, without false alerts on those isolated motion trials.
- The device must also run for at least 8 hours of continuous active monitoring on a single battery charge.
- The fully assembled device, with both IMU boards, the main PCB, and the battery, must weigh less than or equal to 25 grams total, so its own weight doesn't shift sensor placement or throw off calibration.

2 Design

2.1 Block Diagram

Figure 2 shows the five subsystems involved: Sensing, Processing & Control, Feedback, Power, and the extra goal of the Wireless subsystem, with voltage rails and data connections labeled.

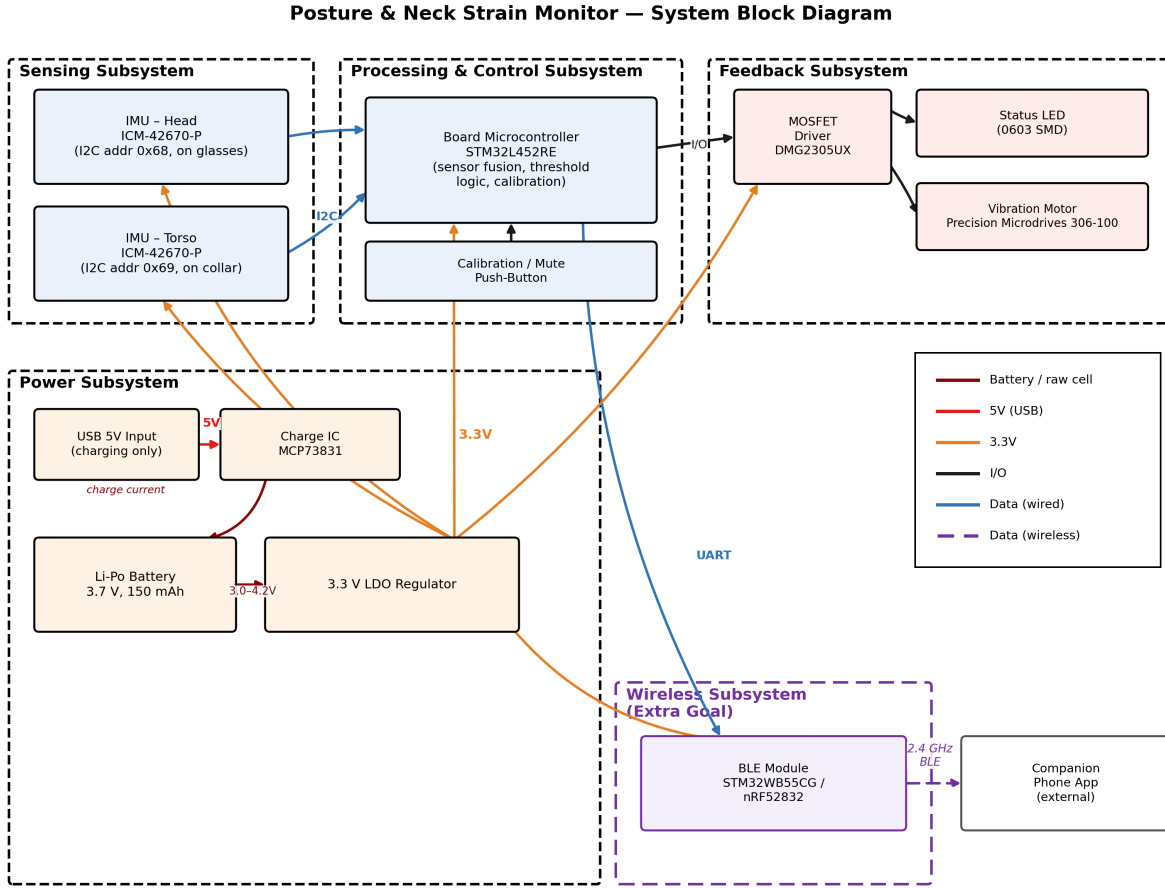


Figure 2: System block diagram, organized by subsystem.

2.2 Subsystem Overview

Sensing: This consists of 2 ICM-42670-P IMUs, with one on the glasses and one on the collar, would share a single I2C bus, split by address using the AD0 pin. They are responsible for handing raw accelerometer/gyroscope data to the processor, which does the actual math to convert that into a relative angle.

Processing & Control. The STM32L452RE would basically be the brain of the system, as it would poll both IMUs over I2C, doing the math to translate the data into a relative angle, checks it against the calibrated baseline, and fires an alert if you've been out of range too long. It would also handle the calibration/mute button and feed data to the BLE module over UART if we decide to pursue the extra goal.

Feedback. When the processor flags bad posture, a GPIO switches a MOSFET (DMG2305UX)

that drives both the vibration motor and the status LED off the 3.3V rail, so the processor itself doesn't have to source that current.

Power. A 3.7V/150mAh LiPo cell feeds a 3.3V regulator that powers everything else, and an MCP73831 handles charging over USB. Basically every other subsystem depends on this one working correctly.

Wireless (extra goal). A BLE module (STM32WB55CG or nRF52832) talks to the MCU over UART and pushes posture data out to a phone app over BLE. This is currently optional, as the core device would work fine without it.

2.3 Subsystem Requirements

2.3.1 Sensing Subsystem

- Both IMUs share one I2C bus at 400 kHz or faster, with distinct addresses (0x68/0x69) set via AD0 so there's no collision.
- Each IMU has to output at least 50 Hz so the fused angle updates fast enough to hit the 1 second alert requirement.
- Accelerometer range $\geq \pm 4g$, gyroscope range $\geq \pm 250^\circ/\text{s}$, so a normal fast head turn doesn't clip the signal.
- The head to shirt wire (I2C + 3.3V + GND, roughly 30 cm) has to survive constant flexing from head movement without cutting out.

2.3.2 Processing & Control Subsystem

- MCU samples and combines IMU data at ≥ 50 Hz and checks the threshold every sample, so an alert can fire within 1 second of a 10 second sustained deviation.
- Firmware has to ignore single axis deviations, such as just glancing down, or just shifting your torso. Only a real head and torso mismatch should trigger an alert.
- Button input is debounced and resets the baseline in one press. Firmware, sensor fusion, and (potentially) the BLE stack all have to fit in the STM32L452RE's 512 KB flash / 160 KB SRAM.

2.3.3 Feedback Subsystem

- The vibration motor has to be noticeable within 3 seconds of activation, and our target is 8/10 test users noticing it that fast.
- The MOSFET gate has to fully switch from a 3.3V logic level GPIO signal, with no extra gate driver needed.
- Needs a mute mode (same button) that kills the vibration/LED alert without turning off the actual posture monitoring underneath.

2.3.4 Power Subsystem

- Regulator has to hold 3.3V $\pm 5\%$, as the IMUs only tolerate 1.71-3.6V, and I2C gets flaky outside that range.

- Average current draw has to stay under roughly 19 mA so the 150 mAh battery lasts the full 8 hours ($150 \text{ mAh} / 8 \text{ h} \approx 18.75 \text{ mA}$); Section 2.4 checks this against our real estimate.
- Charging current out of the MCP73831 can't exceed the cell's rated maximum (about 1C, i.e. $\leq 150 \text{ mA}$).

2.3.5 Wireless Subsystem (Extra Goal)

- BLE traffic can't drop the sensor fusion loop below the 50 Hz minimum.
- Less than 5% data loss over a continuous 30 minute BLE session.
- Runs off the same 3.3V rail as everything else, and can be disabled without touching core posture monitoring if it ends up drawing too much power.

2.4 Tolerance Analysis

The biggest technical risk here is whether our double IMU system is actually accurate enough to tell a real 15° slouch apart from sensor noise, as this is the exact failure mode we are trying to improve on from single IMU devices in the Problem section, so we wanted to check the math instead of just assuming it works. Two error sources matter: gyro noise integrating into angle error over time, and accelerometer noise messing up the gravity reference tilt estimate each IMU uses to correct gyro drift.

Gyro noise: The ICM-42670-P's gyro noise density is $7 \text{ mdps}/\sqrt{\text{Hz}} = 0.007^\circ/\text{s}/\sqrt{\text{Hz}}$ [4]. That converts to an angle random walk of $\text{ARW} = 0.007 \times 60 \approx 0.42^\circ/\sqrt{\text{hr}}$. Over our 10 second hold window ($t \approx 2.78 \times 10^{-3} \text{ hr}$):

$$\sigma_{\text{gyro}}(10\text{s}) = \text{ARW} \times \sqrt{t} = 0.42 \times \sqrt{2.78 \times 10^{-3}} \approx 0.022^\circ$$

This is much smaller than our 15° threshold, so gyro noise should not be a problem.

Accelerometer noise: Accelerometer noise density is $200 \mu\text{g}/\sqrt{\text{Hz}}$ [4]. Assuming roughly 10 Hz of effective bandwidth for the slow gravity-reference channel:

$$\text{RMS noise} \approx 200 \times 10^{-6} \text{ g} \times \sqrt{10\text{Hz}} \approx 6.3 \times 10^{-4} \text{ g}$$

which gives a tilt error of about $\theta_{\text{error}} \approx a_{\text{noise}}/g \approx 0.036^\circ$ per IMU. With two IMUs contributing independently, the combined RMS tilt error is $\theta_{\text{total}} = \sqrt{0.036^2 + 0.036^2} \approx 0.051^\circ$.

Combining both of these potential errors: $\sqrt{0.022^2 + 0.051^2} \approx 0.056^\circ$, which is significantly smaller than our 15° threshold. Even with a few degrees of error from potential mounting misalignment or cable flex we'd still have over about 10° of margin.

3 Ethics, Safety and Societal Impact

3.1 Ethical Considerations

A few parts of the IEEE Code of Ethics [1] apply directly here. The Code puts public safety, health, and welfare first, so we're framing this as a posture awareness device, not a medical one, as we're not diagnosing or treating anything, and we'll tell anyone with real pain to see a doctor instead of relying on us. The Code also expects honesty about claims, so we're only going to say the device hits our expected detection rate and battery life numbers once we've actually tested it against our own criteria for success, not before. The ACM Code [2] adds a privacy angle: since the extra goal of BLE logging touches health adjacent data, we would keep it on the device itself by default and not add any camera or microphone, which also directly answers the privacy complaint we raised about camera based competitors in the Problem section.

3.2 Safety and Regulatory Standards

The biggest safety concern is the LiPo battery, as a damaged or overcharged cell can potentially catch fire. The MCP73831 handles under voltage lockout and charge regulation, but we're also following the department's LiPo safety practices by fireproof charging bags, never leaving a charging cell unattended, and immediately retiring any cell that gets swollen or damaged. We're keeping standards like IEC 62133 and UN 38.3 in mind for cell selection, even though we're not pursuing formal certification for a class project. If we build the BLE piece, we'll also use pre-certified modules (STM32WB55CG/nRF52832) on the unlicensed 2.4 GHz band under FCC Part 15 instead of rolling our own RF front end to avoid compliance headaches. Since the device sits against skin for hours at a time, the enclosure needs non-toxic, hypoallergenic material with no sharp edges, and our ≤ 25 g / compact size requirements double as safety requirements, since a heavy device could cause its own strain with negative side effects. Everything runs off a less than 5V battery rail, so shock risk is very low, but we will still make sure to keep exposed traces away from skin contact.

3.3 Societal, Economic, and Environmental Impact

If this works, it's a decent shot at reducing a common problem, as over half the students in [3] reported neck pain recently in their study. Unlike camera based competitors, we would not be recording any video, which matters in shared spaces like dorms and in places with strict data privacy laws. It's also much cheaper to build than a subscription app or a smart chair, which matters for students who can't afford recurring costs or subscriptions. On the environmental side, a small battery and simple BOM results in a much smaller e-waste footprint as compared to bigger smart furniture products, and we'll still plan to recycle the LiPo cell properly instead of tossing it. Also, since remote and hybrid work/learning is more commonly seen around the world now, a cheap, subscription free, and camera free device works well across very different budgets and privacy regulations.

References

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