ChillPod

Portable Relief for Migraine Headaches

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2 Motivation

Migraines are one of the most common neurological disorders, affecting nearly one billion people worldwide and ranking as the third most prevalent medical condition Mudassir et al., 2024. In today's fast-paced environment, long hours in front of screens, high stress, irregular sleep, and environmental triggers increase their frequency. For many, migraines are recurring, disabling events that disrupt daily life.

The impact of migraines goes beyond pain. Sufferers often experience nausea José Areia, 2023, vomiting, or sensitivity to light and sound, making work, study, or routine tasks difficult. On a larger scale, migraines lead to millions of lost workdays, higher healthcare costs, and reduced productivity, while also affecting emotional well-being, social engagement, and overall quality of life.

Medication is the most common treatment, but it is not always sufficient. Side effects and inconsistent relief drive the need for safer, practical alternatives Elgamal, 1985.

Cold therapy is a well-known method for headache relief, helping reduce pain, regulate blood flow, and promote relaxation. Non-invasive, drug-free, and usable as symptoms appear, it is an effective complementary approach.

ChillPod builds on this principle. This portable cooling device targets stress-related headaches and mild migraines. Lightweight, reusable, and comfortable, it can be used at home, at work, or while traveling. Its simplicity allows immediate use without preparation or assistance, giving users more control and independence. Beyond easing physical pain, it can also help reduce stress and anxiety associated with migraines.

Our goal is to provide a practical, everyday tool for migraine management. Even small improvements can make a meaningful difference, helping patients regain control over their health, maintain productivity, and improve their quality of life.

3 ChillPod

3.1 System design

ChillPod is a compact dual-channel cooling system developed to maintain precise temperatures in two target zones. In its current prototype, the system is integrated into a wearable headphone-like form that fits comfortably on the head. It combines active cooling with intelligent control, enabling personalized adjustment of cooling intensity. The device can be monitored and controlled wirelessly through a dedicated mobile application, giving users flexibility and ease of use.

3.1.1 Hardware

The hardware design is based on a compact control board built around the ESP32-S3 microcontroller. The system integrates Peltier elements, cooling fans, and NTC thermistors for temperature feedback. Power management is provided through a lithium-ion battery with a dedicated charging module, while MOSFETs ensure efficient switching of both Peltiers and fans.

Figure 3.1 shows the schematic of the control circuit, highlighting the main design blocks: microcontroller logic, driver stages for the Peltier elements and fans, and the temperature sensor interfaces.

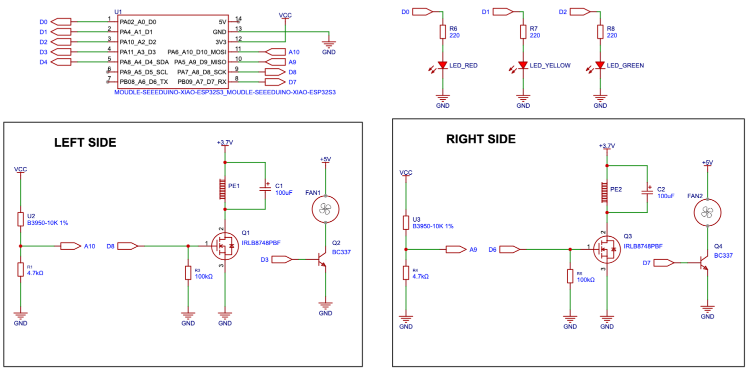

Figure 3.1: *Schematics of control circuit*

The schematics was implemented as custom printed circuit boards (PCBs), designed for compactness and modularity. The manufactured PCBs are shown in Figure 3.2, highlighting the component layout and connectors for the main system parts.

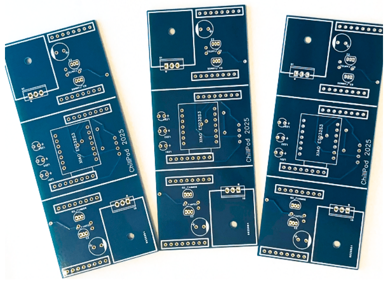

Figure 3.2: *Manufactured PCBs of ChillPod Control circuit*

3.1.2 PID-Based Temperature Control System

For this project, a proportional–integral–derivative (PID) controller was chosen over a simple on/off control strategy. Unlike binary switching, PID allows smoother and more stable temperature regulation by continuously adjusting the Peltier duty cycle based on both current and past errors, as well as predicted trends. This minimizes overshoot, improves responsiveness, and ensures that the target temperature is reached efficiently.

The microcontroller regulates two Peltier elements with independent PID controllers, while Bluetooth Low Energy (BLE) allows remote adjustment of target values and real-time monitoring.

Temperature Measurement: Two NTC thermistors provide continuous temperature feedback. The ADC value is converted to resistance and mapped to temperature using a lookup table.

PID Regulation: Each channel (left and right) runs its own PID loop. The controller minimizes the error between the *target temperature* (received via BLE) and the *measured temperature*.

3.1.3 Mobile App

The ChillPod mobile application (Figure 3.3) connects to the device via Bluetooth Low Energy (BLE), enabling users to control and monitor their therapy sessions seamlessly. Through the app, users can view a personalized calendar that tracks headache-free days and migraine occurrences, set the target temperature and treatment duration, and start, pause, or stop the healing process while monitoring real-time progress with a count-down timer. After each session, users can record their pain intensity on a scale ranging from “No Pain” to “Worst Pain.” The app also provides motivational feedback, such as celebrating consecutive headache-free days, and securely stores session data for ongoing tracking and sharing with healthcare professionals.

3.1.4 Working prototype

The working prototype demonstrated stable cooling performance, maintaining a temperature of approximately 10 °C for around 10 minutes without skin contact, and about 6 minutes when applied directly to the skin.

In migraine therapy, safe and effective cooling typically ranges between 10 °C and 18 °C for durations of 5 to 25 minutes. Therefore, these parameters were adopted for

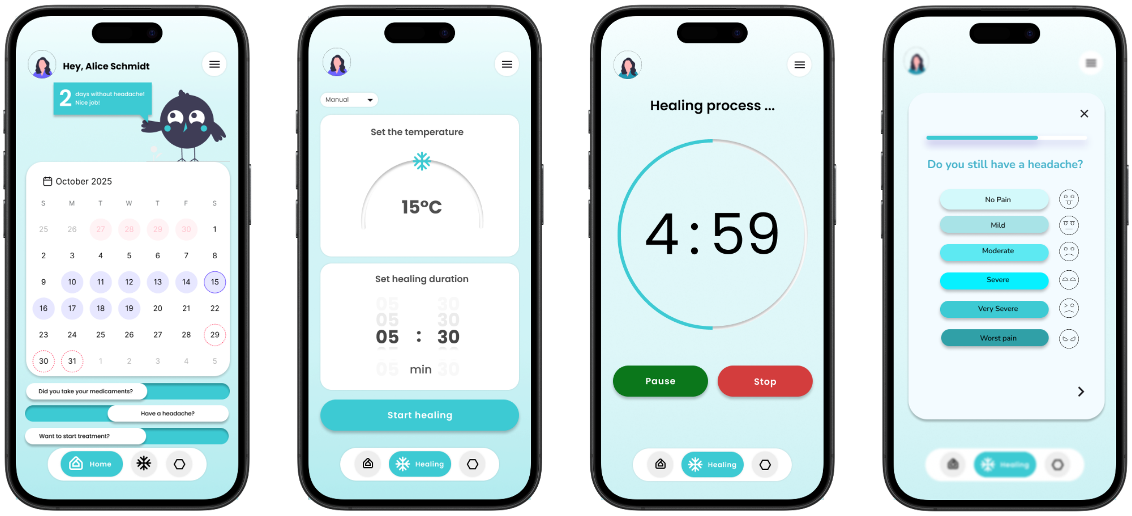

Figure 3.3: *App design*

our device to ensure safe and reliable performance.

Figure 3.4: *Working Prototype*

3.2 Workflow and Challenges

3.2.1 Evolution

The mechanical design evolved in parallel with the testing and development process. Initially, the device was envisioned to resemble ear pods, with a main case containing two detachable cooling pads that could be applied independently to different areas of the head. However, due to challenges with heat dissipation, power consumption, and limited development time, this compact concept was postponed as a future direction. For the current working prototype, a headphone-style design was selected, featuring fixed cooling pads that target the head area.

The overall development path of the device is illustrated in Figure 3.5, which shows the transition from the initial concept to the functional prototype. Further details are discussed in the following subsections.

The first stage of development focused on testing and fine-tuning the parameters required for Peltier control and identifying suitable materials for skin contact. After initial setup and prototype testing, multiple configurations were evaluated through user trials to determine the most effective parameters. To implement PID control, the temperature sensors were calibrated using a more precise reference sensor, ensuring accurate thermal response and user safety. Once the electronics were optimized, the integration stage combined the temperature sensors, Peltier elements, and control circuitry on a compact breadboard layout.

The following phase involved 3D printing a custom-fit casing designed to securely house all components while maintaining a clean, ergonomic appearance. During final assembly, all mechanical and electronic elements were integrated into a headband-style structure, completing the functional prototype.

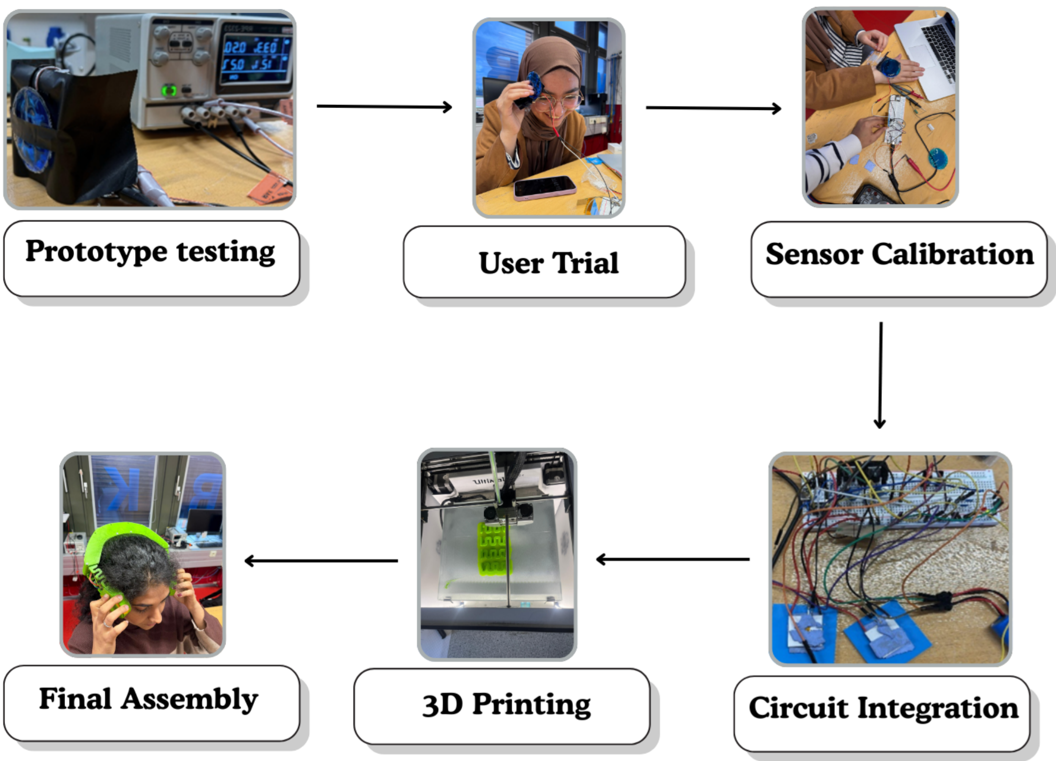

Figure 3.5: *Development stages of the ChillPod device.*

3.2.2 Thermoelectric cooler control

The goal of this stage was to establish efficient and stable control of the Peltier element to achieve effective cooling while minimizing power losses and heat buildup.

For the demonstrator, the TEC1-4905 Peltier element was selected. Initial tests were conducted to determine the optimal power characteristics of the module, focusing on voltage, current, and heat dissipation. Directly powering the Peltier at full capacity quickly led to excessive heat generation on the hot side, which limited cooling duration and required large heat sinks for thermal stability.

To address this issue, PWM control was introduced to regulate the average power supplied to the Peltier element. The operating voltage was fixed at 3 V, while cooling intensity was adjusted via the PWM duty cycle. This approach improved efficiency and extended operating time; however, high PWM frequencies caused additional heat generation in the MOSFETs.

We also experimented with implementing an LC filter to smooth the PWM signal. However, this approach reduced the effective power delivered to the Peltier element, preventing it from reaching the desired cooling temperature.

The final optimization combined reduced PWM frequency with PID-based temperature control. This setup provided precise temperature regulation, minimized heat buildup, and allowed the use of a smaller heat sink and fan, resulting in a more compact and energy-efficient system.

3.2.3 Material

Another major challenge was identifying a suitable interface material that combined high thermal conductivity with biocompatibility and safety for human skin. Initially, we explored medical-grade adhesive pads, as our early concept involved detachable cooling pads that could be applied directly to the skin. However, most adhesive materials used in medical applications have very low thermal conductivity—typically in the range of 0.1–0.3 W/m·K—which significantly limited the transfer of cooling from the Peltier element.

Next, we experimented with gel pads. While they offer good thermal capacity and skin comfort, their thermal conductivity (approximately 0.3–0.6 W/m·K) was still too low to provide efficient cooling in our setup. After several trials, we identified thermal silicone pads as the most effective solution. With a thermal conductivity of around 13 W/m·K, they provided excellent heat transfer between the Peltier surface and the skin-contact layer, while remaining flexible, non-toxic, and comfortable for prolonged skin contact.

Once the interface material was selected, we designed the initial prototype (Figure 3.6) using a single Peltier element to validate the concept and test cooling performance.

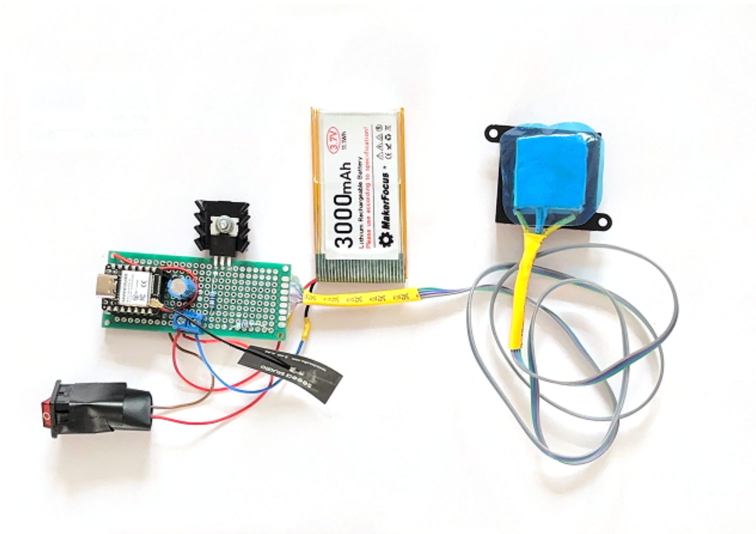

Figure 3.6: *Initial prototype*

3.3 Outlook

The current ChillPod prototype demonstrates the potential of portable cold therapy for headache and migraine relief. Future development will focus on enhancing cooling efficiency, extending battery life, and improving user comfort, including the creation of independent adhesive pads, as illustrated in Figure 3.7. The integration of adaptive control algorithms and expanded app functionality could further personalize the user experience.

Figure 3.7: *Compact cooling pads*

In addition to technical improvements, user studies and clinical validation will be crucial to assess long-term effectiveness and acceptance among migraine patients. Looking further ahead, ChillPod could be adapted for additional applications, such as stress reduction or recovery after physical activity, expanding its potential impact on everyday wellness.

4 Business Model

4.1 Finance

The estimated cost for building a single ChillPod prototype is summarized in Table 4.1. Since the components were purchased in small quantities, prices are slightly higher than they would be for bulk orders. Including additional items such as MOSFETs, resistors (provided by the Working Lab), and other necessary assembly equipment, the total cost per prototype is approximately 80 Euros.

For larger production runs, the unit cost is expected to decrease significantly, potentially reaching around 30 Euros per device, making the design more cost-effective for mass production.

No.	Item	Quantity	Price (Euro)
1	Seeed Xiao ESP32	1	17.79
2	3.7V 3000mAh LiPo Battery	2	15.29
3	Peltier Cooler TEC1-4905	2	7.78
4	Adafruit Extra Thin 10K Thermistor, B3950 NTC	2	15.98
5	Heatsink 50x50x4mm	2	5.675
6	Type-C USB-C TC4056 5V 1A Li-ion Charging Board	1	1.23
7	13W/m.K Thermal Pad 5x5cm	2	3.33
8	Cooling Fan Brushless 5V	2	3.995
9	DC Step-Up Converter, 3.7V to 5V	1	0.60
10	Mini Slide Switch	1	0.23
		Total Price	**71.995**

Table 4.1: *Components required for one ChillPod prototype, with quantities and individual prices.*

4.2 Market Analysis

Migraine management is an active field of innovation, with many products currently available. Most solutions focus on non-pharmaceutical therapies, providing relief through cooling, compression, or a combination of both. Studying these products helps us understand market trends, identify limitations, and highlight the unique value proposition of ChillPod.

4.2.1 Existing Cold Therapy Devices

- **Cefaly** – FDA-approved wearable delivering electrical nerve stimulation for migraine prevention and treatment.
- **TheraICE RX Headache Relief Cap** – Gel-based cap providing hot and cold compression therapy.
- **Aculief Headache Hat** – Fabric cap with removable ice packs for targeted cooling.
- **Oculief & IceWraps** – Eye masks and wraps designed for forehead and eye-area cooling.
- **Nerivio** – Wearable neuromodulation device worn on the arm, controlled via smartphone app.

4.2.2 ChillPod's Unique Features

Criteria	**Wrist Wrap (Therapeutic Device)**Ruiz et al., 2024	**CVS (Neuromodulation Headset)**Black et al., 2016	**ChillPod Migraine Device**
User Environment	Not optimized for mobility	Controlled home trials	Fully portable, self-contained, lightweight device
Power and Control	Wired setup with regulated current	Controlled via external protocol	Compact battery-powered with simple UI
Setup and Operation	Requires manual wrapping, positioning, and mode selection	Pre-programmed clinical interface; users cannot freely modify settings	One-touch or app control, user-adjustable modes, on-demand activation
Cost and Scalability	Expensive materials and complex multi-layer design	High cost due to precision control and sensors	Low to moderate cost, scalable design for mass consumer market

Table 4.2: *Comparative analysis of existing devices and ChillPod.*

4.2.3 Market Observations

Key observations from the current market:

- Most products rely on passive cooling (gel packs, ice wraps), which require pre-freezing and lose effectiveness over time.
- Wearable electronic solutions often focus on neuromodulation rather than precise cold therapy.
- Very few products allow active temperature control, preventing users from setting or maintaining a specific cooling temperature.
- Comfort and portability are common limitations due to bulky designs or reliance on external refrigeration.

4.2.4 Opportunity for ChillPod

ChillPod addresses these gaps by offering:

1. Active cooling using dual Peltier elements, eliminating the need for pre-freezing.
2. Temperature control via smartphone app, allowing personalization and ensuring safe use.
3. Lightweight, wearable headband design for comfort and portability.
4. Integrated fans and smart power management for consistent performance.

By combining these features, ChillPod positions itself as a next-generation migraine relief product that is portable, adjustable, and reliable, meeting the needs of modern users seeking drug-free, on-demand therapy.

5 Marketing

To promote ChillPod and raise awareness among relevant stakeholders, we focused on a marketing strategy centered on social media and university networks.

5.1 Social Media Engagement

- Created an Instagram page to share videos and updates on project development.
- Posted regular updates to engage the audience and visually showcase project progress.

5.2 University Network

Headaches and migraines are common among students in Germany, with 61.8% experiencing migraines, 35.2% tension-type headaches, and 3% related to medication overuse. To raise awareness about ChillPod, the team worked with ASTA student groups to share posts about the project on university platforms. These posts provided information about the device and its potential benefits for headache relief.

A student's experience illustrates its use:

Kendra Leinor: "I had a mild migraine this morning, so I tried ChillPod at 10 °C for five minutes. The relief was almost immediate, and I felt much more comfortable afterward."

5.3 Outcome and Impact

By combining social media and university network efforts, we successfully raised awareness about ChillPod and engaged the student community. The positive responses and student testimonials demonstrate early interest and potential adoption. This approach ensured that students, faculty, and peers were informed about the benefits and innovations of our device, laying the groundwork for further engagement and feedback.

6 Summary

The ChillPod 2025 project presents a portable cold therapy device designed to provide fast, drug-free relief from migraines. With migraines increasingly common due to long screen hours, stress, and irregular sleep, there is a growing need for wearable, non-pharmaceutical solutions.

ChillPod uses two Peltier modules positioned on either side of the forehead, each paired with a fan and heatsink for efficient cooling. Temperature sensors monitor the system, while the Seeed Studio XIAO ESP32-S3 microcontroller independently controls each Peltier via PWM-driven NMOS transistors. Users can adjust settings and track performance through a Bluetooth-enabled smartphone app, making the device intuitive and convenient.

The PCB layout separates the microcontroller from the high-current Peltier and fan circuits, improving safety and reliability. LED indicators provide real-time feedback on device status.

During development, we addressed challenges such as uneven cooling, high current draw, and inefficient heat dissipation. The mechanical design evolved from an earpod-style concept to an ergonomic headband, ensuring comfort and ease of use.

Compared to existing migraine relief products like Cefaly, TheraICE RX, and Headache Hat, ChillPod offers active, controllable cooling without the need for pre-freezing. Its portability, precise temperature control, and smart operation make it a modern, user-friendly solution for migraine management.

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