Introduction

Background and Motivation

Heart rate zone training helps users tailor workouts to specific goals like fat burning, endurance, or peak performance. However, many lack access to affordable tools that provide real-time zone feedback. Existing solutions, such as smartwatches and chest straps, are often expensive, complex, or require smartphone connectivity, while budget options typically show only raw BPM. To address this gap, we developed a standalone, low-cost wearable that delivers intuitive, real-time heart rate zone feedback using LED and haptic cues, without needing a smartphone.

Project Scope and Features

The goal of this project was to design and prototype a self-contained wearable device that classifies and displays the user's current heart rate zone. The device targets beginner and budget-conscious runners, as well as users who prefer distraction-free workouts. Secondary users include coaches and healthcare professionals who use HR zone data. The final system includes:

- A five-colour LED array to indicate the current HR zone
- A vibration motor to notify users during zone transitions
- An LCD screen and button interface for entering age and resting heart rate (RHR)
- Real-time on-screen display of BPM and HR zone classification

The primary objectives of this project were to:

- Measure HR within ±3 BPM of a validated device (e.g., Apple Watch)
- Provide immediate, on-device feedback, with easy user input
- Support at least 12 hours of battery life
- Ensure comfort, wearability, and usability, targeting a weight of 50-80 g

- Operate reliability across -5 °C to 45 °C and offer basic sweat/water resistance
- Maintain total cost under $100

These goals were shaped by constraints, such as Arduino pin limitations, noisy sensor data due to motion, compact design requirements, and low-cost component sourcing.

As the project progressed, several aspects evolved:

- We replaced the planned rotary knob with a more flexible button-based LCD interface.
- The HR sensor was moved from wrist to finger placement for better signal stability.
- A 3D-printed wristband was replaced with an EVA foam forearm brace for improved fit.
- A planned voltage divider for the motor was dropped due to integration complexity.

Team Roles and Collaboration

Our six-member team divided responsibilities by subsystem. Annie Cai developed the core heart rate zone logic, including max HR and zone classification, and integrated it into the system. Avital Palchik implemented the heart rate sensor and supported LCD testing. Jacqueline Fung built the LED indicator and led the software architecture. Michelle Wang designed and fabricated the wearable brace. Sonia Wu implemented the buzzer and power system and assembled the hardware. Olivia Cesta developed the LCD and button interface for user input and zone display.

Report Outline

This report documents our full design process and outcomes. The next section details each team member's individual contributions, followed by a discussion of how we integrated all subsystems into a cohesive prototype. We then evaluate the effectiveness of our testing and reflect on our workflow and collaboration. The report concludes with an assessment of limitations and outlines potential future directions for improvements.

Individual Contribution: Michelle Wang

I was responsible for designing both the forearm brace and the hardware enclosure. The forearm brace was relatively straightforward: I selected EVA foam for its comfort and flexibility, and integrated adjustable buckles to ensure a customizable fit across a range of users (see Appendix Figure 3).

The hardware enclosure was modeled in Fusion 360 and prepared for printing in PrusaSlicer, using PLA filament on printers at the Rapid Prototyping Centre. One of the key design challenges was developing an effective closure mechanism. The initial version featured a snap-fit design (see Appendix Figure 4), but it was very difficult to close and the joints eventually snapped. To improve the fit on the brace, I also needed to adjust the enclosure's curvature by reducing the radius. In the second iteration, I redesigned the enclosure with a hinge on one side and a snap-fit joint on the other, greatly improving usability (see Appendix Figure 5).

Once the components were complete, I assembled the prototype, tested it with the hardware installed, and everything fit securely (see Appendix Figure 6). However, I experienced a few usability issues: the button sticks were prone to jamming or slipping if pressed too quickly or forcefully. They also complicated the closing process, as the enclosure had to be closed upside down to prevent the buttons from falling out. Additionally, the brace's tightest adjustment was still a bit too loose for users with slimmer forearms, so I should have either made the brace narrower or allowed for tighter adjustment settings. For future iterations, I would also explore alternative materials with better sweat resistance, considering the user is likely to sweat while running. Overall, this project reinforced the importance of precision, iterative prototyping, and planning for edge cases. It provided valuable hands-on experience in 3D design, digital fabrication, and user-centered testing.

Design Integration

Our prototyping process combined both incremental and evolutionary prototyping to efficiently develop and refine our system. We began with an incremental approach, dividing development among key hardware components such as the LED, LCD display, heart rate sensor, and buzzer. Each module was designed and tested in isolation to ensure functionality before integration. Once the individual parts were functioning, we transitioned to evolutionary prototyping, gradually combining the components and refining the system through iterative testing. We started with basic interactions, such as controlling the LED via keyboard input, then linked the LED to heart rate zone calculations, added a buzzer to indicate zone changes, replaced keyboard input with real data from the heart rate sensor, transitioned from a breadboard to a more permanent perfboard, and finally integrated the LCD to allow user input for setting values instead of relying on hard-coded constants.

Throughout this process, hardware and software changes were closely coordinated, with each refinement in one area coupled by updates in the other. Key decisions, such as the sequence of integration, testing methods, and when to transition to permanent hardware, were made collaboratively to ensure smooth progression. Frequent group meetings to synchronize and decide on next steps together helped maintain system functionality through each iteration. The process concluded with the construction of the physical brace, bringing all components together into a cohesive and testable final prototype. This blended approach allowed us to validate modules thoroughly early on while staying flexible and adaptive as the system evolved into a fully functional device.

Testing and Evaluation

We tested the prototype for feasibility and functionality in two stages. First, we evaluated individual components using rapid, exploratory prototypes to ensure basic functionality. Once these were reliable, we tested the full system using a developmental process, focusing on the brace and enclosure, which needed a secure fit for accurate sensor readings. Our key questions were whether this prototype is feasible, and whether it solves the problem at hand. We determined cost feasibility using our bill of materials and pricing, and tested whether the system indicated heart rate zone changes correctly (Appendix Figure 7). While the current version is bulkier and resembles a brace more than a watch, it performs reliably and can be scaled down. We compared results to the original constraints: a BPM accuracy within ±3 BPM, a weight of 50 to 80g, a flexible, size-adjustable band, and a rechargeable battery. The prototype achieved a ±2.5 BPM accuracy, a weight of 239g, includes an adjustable strap, but is not yet rechargeable. We also had 10 users walk with the prototype for 10 minutes in order to test real-world use. Most found that the brace caused discomfort and sweating, and would prefer a smaller interface. However, they liked the combination of LED and haptic feedback, and found it helpful to see BPM and zone in real time. To test for heart rate accuracy, we used a within-subjects test across various activity levels, and logged BPM every 10 seconds; results showed that the average difference in BPM was ±2.5 (Appendix Figure 8).

Based on these results, we developed some next steps, including redesigning the prototype as a smaller, more wearable form using compact microcontrollers and displays. Some suggested improvements, like reducing size, could not be implemented due to time and resource limits. Each team member tested their own subsystem, and Avital coordinated full-system evaluation. Testing will continue as we move toward a refined prototype and eventual pilot.

Team Workflow & Collaboration

Our team maintained clear and consistent communication throughout the project using several key tools. Discord was our primary communication platform for daily coordination and real-time troubleshooting. We used GitHub to manage our codebase and avoid merge conflicts, Google Drive to share documents and organize files, and Google Calendar to schedule meetings.

Each team member developed their subsystem through an iterative process, prototyping, testing, and refining their work before integration. Once all components were brought together, we continued to iterate as a team, refining logic and tuning behaviors through collective feedback. For instance, we adjusted the buzzer logic from three buzzes to one for simplicity, and revised the heart rate zone logic to better handle values above the maximum zone. These small but critical refinements helped us ensure a smoother and more intuitive user experience.

When individual tasks were dependent on others, we avoided bottlenecks by setting clear internal deadlines and milestones, which helped each member complete their part on time. When delays arose, we communicated transparently about the issues and their impact, allowing teammates to adjust timelines as needed. This helped maintain team trust and ensured downstream work was not stalled unnecessarily. In situations of disagreement or design trade-offs, we typically discussed the issue as a group. One example was deciding how to handle invalid HR readings. These decisions were always made with group consensus in mind, and we maintained a highly collaborative environment throughout the project.

Overall, our workflow emphasized clarity, accountability, and adaptability, which enabled us to stay aligned and deliver a fully integrated, functional prototype on time.

Conclusion

Through the application of incremental and evolutionary prototyping methodologies, our team successfully developed a wearable heart rate zone calculator within the set budget of $100, integrating both haptic feedback (via a buzzer), simple visual feedback (via LEDs), and more comprehensive visual information through an LCD shield. The resulting device is designed to be worn on the user's wrist and was constructed as a functioning prototype, thereby demonstrating our ability to transfer conceptual ideas to a physical, testable system. We also stayed under our prototyping budget of $100. This process was marked by effective team collaboration across stages of ideation, modeling, construction, and iteration, mirroring best practices in engineering design and prototyping as emphasized throughout the course.

Despite these achievements, several limitations were encountered, both in concept and construction. Drawing on insights from the "Human Factors Considerations in the Design of Wearable Devices" report, our device presently falls short in terms of aesthetics and ergonomics, largely due to component selection and available resources [4] . Specifically, the use of the Arduino Uno R3, paired with a standard LCD shield, dictated a larger form factor, necessitating a forearm-mounted device rather than a sleek wristband. This constraint emerged from our choice to minimize costs by utilizing existing, readily accessible hardware—which, while cost-effective, limited our exploration of microcontroller options and contributed to suboptimal size and weight. The physical assembly also highlighted material limitations; for example, constructing the enclosure from EVA foam posed challenges in achieving a comfortable and secure fit, as well as long-term durability under varied conditions. EVA foam, while lightweight, offered limited breathability and was not ideally suited for use during high-intensity physical activity. Moreover, the attachment methods (primarily glue) may not provide sufficient robustness for sustained outdoor use or exposure to sweat and extreme temperatures.

Looking ahead, several avenues for future development have been identified to overcome current limitations and advance the prototype towards a more refined, market-ready device. A key objective would be to miniaturize the form factor by selecting a more compact microcontroller, or a dedicated wearable development board, and incorporating a smaller, more energy-efficient LCD display. Additional design iterations should address enhanced user comfort and aesthetics by evaluating alternative, breathable strap materials, and optimizing enclosure shape and assembly techniques. With more money, and abilities to source different sensors, we also would want to integrate advanced sensors for improved heart rate accuracy. Additionally, given more time, we also would like to use a rechargeable battery and make the device easily rechargeable, and develop an onboard power switch for convenience, insteading of needing to unplug the power. Currently, we are limited to test the full capacity of the battery since if we drain it, we would need to purchase another. Subsequent user testing, in line with the twenty wearable device principles discussed in the course, would inform ergonomic and functional refinements, as well as validate usability and comfort in both controlled and real-world settings, including testing for sweat-resistance and extreme weather performance [4]. Lastly, scaling the device could involve the inclusion of Bluetooth connectivity for mobile synchronization, upgrading the LCD to support full color for a more intuitive interface, and implementing basic security features to protect user data. Addressing these areas would not only enhance user experience but also increase the device's applicability for long-term use in athletic and health monitoring scenarios, laying the groundwork for potential commercialization or extended research trajectories.

References

[1] P. T. Nikolaidis, T. Rosemann, and B. Knechtle, “Age-Predicted Maximal Heart Rate in Recreational Marathon Runners: A Cross-Sectional Study on Fox’s and Tanaka’s Equations,” *Frontiers in Physiology*, vol. 9, no. 226, Mar. 2018, doi: https://doi.org/10.3389/fphys.2018.00226.

[2] Ignaszewski, M, et al. “The Science of Exercise Prescription: Martti Karvonen and His Contributions.” *British Columbia Medical Journal*, vol. 59, no. 1, 1 Jan. 2017, pp. 38–41, www.researchgate.net/publication/313718081_The_science_of_exercise_prescription_Martti_Karvonen_and_his_contributions.

[3] “What is heart rate reserve?,” *Cleveland Clinic*, 2023. https://my.clevelandclinic.org/health/articles/24649-heart-rate-reserve

[4] V. G. Motti and K. Caine, “Human factors considerations in the design of wearable devices,” *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 58, no. 1, pp. 1820–1824, Sep. 2014. doi:10.1177/1541931214581381

Appendix

```
int getMaxHeartRate(int age) {
  return (int)(208 - 0.7 * age);
}

int getCurrentZone(int heartRate) {
  int maxHR = getMaxHeartRate(age);
  int HRR = maxHR - rhr;

  float zones[][2] = {
      {0.50, 0.60}, // Zone 1
      {0.60, 0.70}, // Zone 2
      {0.70, 0.80}, // Zone 3
      {0.80, 0.90}, // Zone 4
      {0.90, 1.00}  // Zone 5
  };

  int zone1Lower = rhr + HRR * zones[0][0];
  int zone5Lower = rhr + HRR * zones[4][0];

  // If below Zone 1
  if (heartRate < zone1Lower) {
    return 0;
  }

  // Zones 1 to 4
  for (int i = 0; i < 4; i++) {
    int lowerBound = rhr + HRR * zones[i][0];
    int upperBound = rhr + HRR * zones[i][1];

    if (heartRate >= lowerBound && heartRate < upperBound) {
      return i + 1;
    }
  }

  // Above Zone 5
  if (heartRate >= zone5Lower) {
    return 5;
  }
  return 0;
}
```

Figure 1. Code for heart rate zone calculation

Figure 2. LCD Display

Figure 3. Wrist brace design

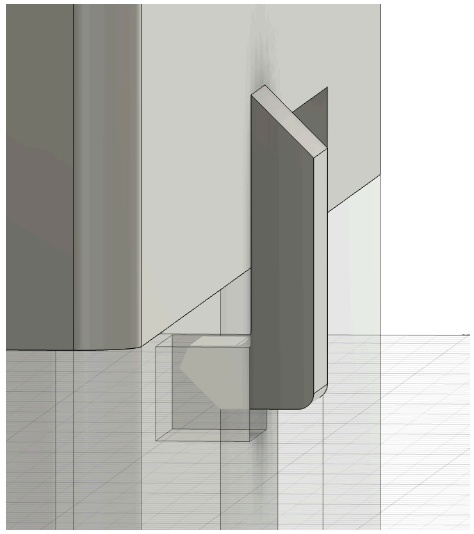

Figure 4. Initial snap-fit joint design

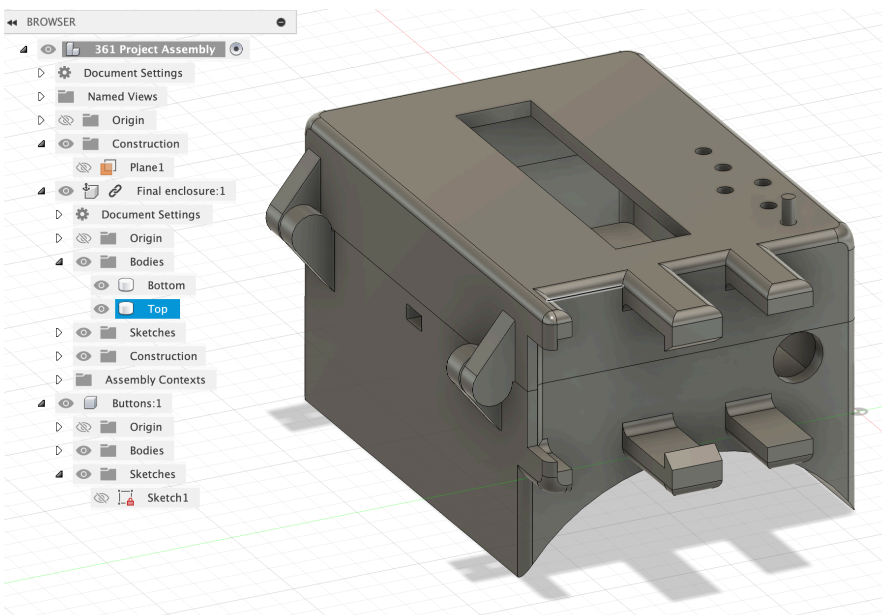

Figure 5. Second iteration with hinge mechanism

Figure 6. Final prototype

Line Item	QTY	Part Description	Source	Source Part Number	Unit Price	Shipping Cost	Taxes	Total Cost	Li
1	1	9V Battery	Amazon	B00MH4QM1S	$2.38	$0.00	$0.31	$2.68	
2	1	Velcro	Amazon		$15.36	$0.00	$2.00	$17.36	
3	1	Heart Rate Sensor - DF ROBOT/ SEN0203	DigiKey	17338-1192	$19.11	$27.45	$2.85	$49.41	
4	1	Coin buzzer	Amazon	B0BVMJ962F	$0.99	$0.00	$0.13	$1.12	
5	1	PLA Filament	Rapid Prototyping Lab	-	$1.98	$0.00	$0.00	$1.98	
6	1	LED Light	Lab Kit	-	$0.00	$0.00	$0.00	$0.00	
7	1	Arduino Uno	Lab Kit	-	$0.00	$0.00	$0.00	$0.00	
8	1	Arduino LCD Shield	Lab	-	$0.00	$0.00	$0.00	$0.00	
9	3	220 Ohm Resistors	SYDE Lab						
							Total Spent	$72.55	

Figure 7: Bill of Materials with total cost we spent out of pocket

Trial Results

Trial	Zone	Prototype BPM	Reference BPM	Difference (±BPM)
1	0	72	74	2
1	1	132	136	4
1	2	141	145	4
2	0	80	78	2
2	1	137	135	2
2	2	150	154	4
3	0	76	77	1
3	1	130	128	2
3	2	144	147	3
4	0	71	73	2
4	1	129	131	2
4	2	151	149	2
5	0	79	80	1
5	1	133	136	3
5	2	146	148	2

Figure 8. Results of BPM accuracy testing