CURLING ASSISTANT FOR VISUALLY IMPAIRED (CAVI)

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Abstract—This paper introduces IceAlign, an assistive technology system designed to enable visually impaired athletes to participate in precision sports like curling. The system addresses the challenge of auditory clutter by replacing verbal alignment cues with a synchronized infrared (IR) beam and radio frequency (RF) communication network. Our prototype consists of three modules: Skip's Module (IR emitter), Thrower's Module (IR receiver), and Sweeper's Module (feedback mechanism). The prototype was successfully designed, developed, and tested in actual curling environments, achieving alignment accuracy of ±5 cm at distances up to 20m and communication latency below 10ms. Testing confirmed the system operates reliably in temperatures from -10°C to +40°C and withstands over 1,000 rapid sweeping motions. The working prototype demonstrates that sensor-based assistive systems can effectively translate visual coordination into accessible feedback, creating new opportunities for inclusive participation in precision sports

Keywords—assistive technology,* auditory clutter *,RF communication, inclusive design, adaptive sports, real-time feedback.

I. INTRODUCTION

Growing up , we learned that challenges demand a creative solution , questions like why does a stone roll downhill? Why does a leaf float? Sparked a curiosity that drive our engineering journey. Today, I want to start this paper by asking questions: *How can technology empower people with disabilities to compete in precision sports like curling?.*

Precision sports such as curling rely heavily on visual coordination between players—a significant barrier for visually impaired athletes. Currently, these athletes depend on auditory cues—verbal instructions, ambient sounds—for guidance. . However, this approach introduces **auditory clutter**—competing signals from teammates, spectators, or environmental noise—that confuses the thrower during critical aiming phases, degrading accuracy and team synchronization [4].This limitation stems from the absence of a dedicated, unambiguous feedback mechanism for alignment, a gap identified by our project sponsor during observational studies of adaptive curling leagues.

To bridge this gap, we introduce IceAlign, a modular assistive system that replaces visual cues with real-time infrared (IR) emitter and receiver for alignment, and radio frequency (RF) for indoor communication between players, enabling athletes to collaborate via audio-tactile and visual feedback.

The system comprises three synchronized modules (Fig. 1):

1. **Skip's Module**: Emits a vertical IR beam (940 nm wavelength, <1 W power) using a TSAL6100 emitter, achieving ±5 cm alignment accuracy over 50 m.

2. **Thrower's Module**: Detects IR signals via a TSOP3448 photodiode relaying confirmation through RF transceivers (NRF24L01) with ≥95% signal integrity at 50 m.[3]

3. **Sweeper's Module**: Activates a Bright LED and buzzer upon beam interruption, providing dual-mode feedback for visibility in bright or noisy conditions.

The system prioritizes Size, Weight, Power, and Cost (**SWaP-C) optimization** for deployment in subzero curling environments. It withstands rapid broom movements (>1000 sweeps at 1.5G force) and maintains stable performance in extreme temperatures (-10°C to +40°C) and high humidity conditions (90%). The components meet waterproofing standards equivalent to IP67.

The potential impact of *IceAlign* extends beyond competitive sports. By enabling visually impaired athletes to participate fully, the technology addresses the social isolation that often accompanies such disabilities. Its modular, replaceable components reduce electronic waste, supporting environmental sustainability. Furthermore, *IceAlign* could establish new design standards and accessibility requirements within the adaptive sports industry.

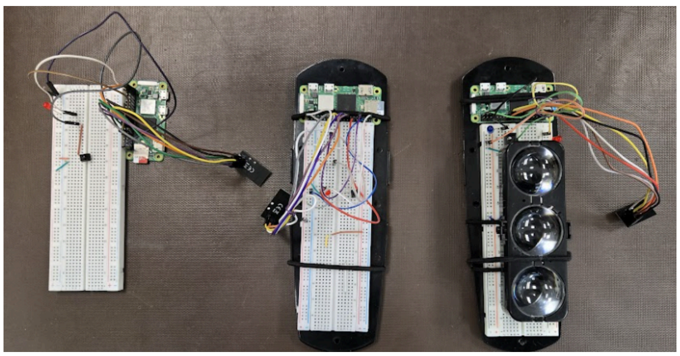


Figure XX: this figure shows the developed module if IceAlign consists of three modules, the rightmost is skips module followed by thrower and sweeper modules.

The remainder of this report is organized as follows: Section 2 outlines our Prototype Design, Implementation, and Results, covering the system architecture, hardware and software development,performance evaluation, and limitation. Section 3 describes potential Future Work, including SWaP-C optimizations and feature enhancements. Section 4 presents our Conclusions, summarizing achievements and lessons learned from the project execution;followed by acknowledgment and references . These sections collectively demonstrate how IceAlign achieves its goal of enabling visually impaired athletes to participate fully in precision sports through innovative engineering solutions

II. PROTOTYPE DESIGN , IMPLEMENTATION AND RESULT

Before describing the final prototype, it is important to note that the design was guided by our initial proposal response. The proposal emphasized a robust IR-based alignment system, a visual and tactile feedback system , and clear communication between the skip, thrower, and sweeper. These key elements influenced our selection of hardware components, power management, and integration strategies, as well as our focus on meeting essential functional and performance requirements

A. Alignment using IR Emitter and receiver

The prototype uses a **high-power IR LED (Vishay TSAL6100)** as the emitter for the alignment system. The TSAL6100 outputs at a peak wavelength of 940 nm with a narrow beam (half-intensity angle of ±10°)[6]. To achieve a **50 m alignment range with ±5 cm accuracy**, the IR beam was optically shaped into a vertical planar fan using collimating lens (Diameter =30mm , focal length = 25.4 mm) so that horizontal alignment is critical while vertical tolerance is increased.Furthermore, **modulation** is applied to the IR LED for both range and noise immunity.he emitter is driven with a 38 kHz square-wave burst (duty cycle ~1/3). This follows manufacturer guidance that a 38 kHz pulsed drive maximizes IR transmission distance,[7]and allows the receiver to filter out ambient light.The IR beam intensity and duty cycle were also chosen to meet **eye safety** requirements; at the maximum drive current (100 mA pulse), the TSAL6100's radiant intensity (~400 mW/sr) remains within the IEC 62471 *Exempt* risk group limits[1][8]

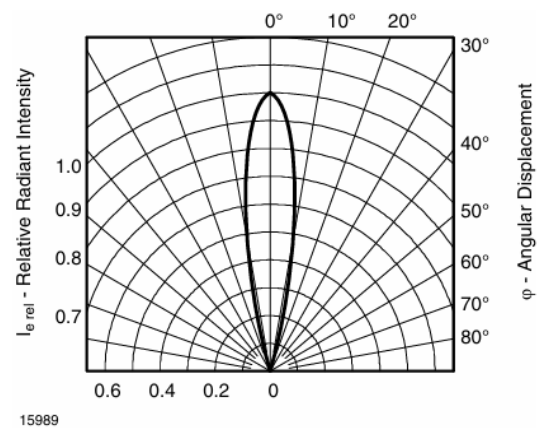


Figure XX: this figure shows Relative Radiant Intensity vs. Angular Displacement before its optically shaped using lenses.[6]

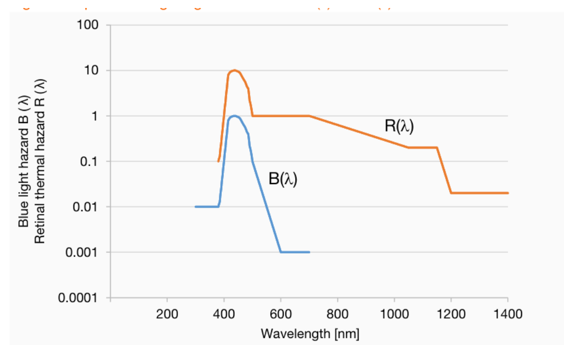
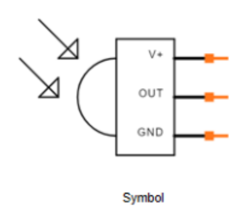


Figure XX: Spectral weighting curves for the R(λ) retinal hazard [1]

On the receiver side, a **Vishay TSOP3448 IR receiver module** (38 kHz bandpass) detects the incoming IR signal. This module integrates a photodiode with an automatic gain control (AGC) preamplifier and a



bandpass filter tuned to 38 kHz, yielding strong immunity against
ambient light noise[2].In other words, constant sunlight or indoor lighting (which is mostly DC or 50/60 Hz) is rejected by the high-frequency filtering, while the pulsed 38 kHz IR beam is reliably detected[10][2].The TSOP sensor's output is fed into a microcontroller for further processing

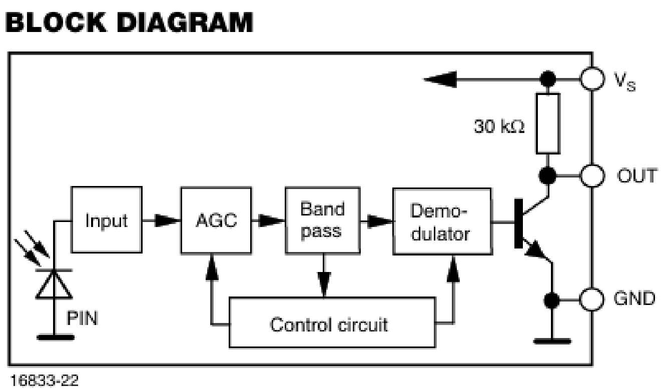


Figure (xx) : this figure shows the block diagram of TSOP34438 photodiode[2].

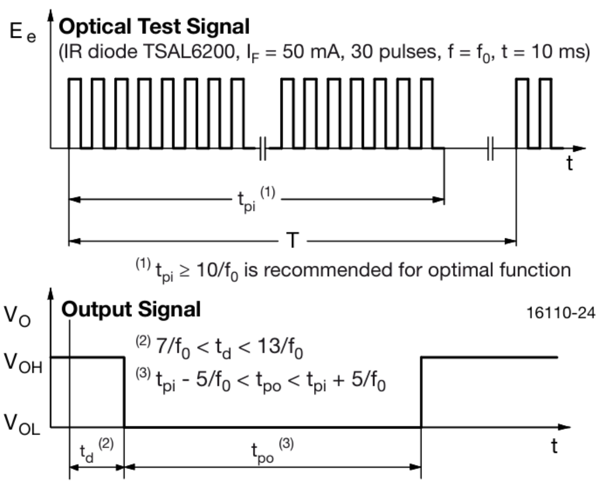


Figure XX This figure illustrates the relationship between the optical input signal and the active low output signal of an IR receiver module[2]

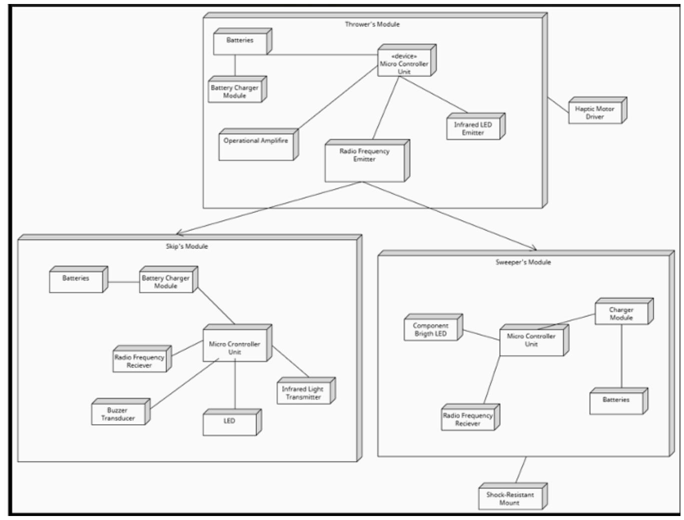


Figure XX: this figure shows the the high level system architecture of IceAlign, It's made of three main nodes that correspond to skip , thrower and sweepers modules

B. Communication using the RF transreceiver

For wireless communication between modules, the design employs the **Nordic nRF24L01+ 2.4 GHz transceiver**. This chip was chosen for its robust performance and low power consumption: it supports multiple data rates (250 kbps, 1 Mbps, 2 Mbps) and uses only about 11–13 mA when actively transmitting. The nRF24L01+ operates in the license-free 2.4 GHz ISM band and uses **Enhanced ShockBurst™[3]** packet handling with built-in error correction and acknowledgment. This allowed the prototype to have a reliable bi-directional link with minimal firmware overhead. Each of the three modules (emitter, receiver, and a secondary alert module) was equipped with an nRF24L01+ and a microcontroller interfaced via SPI.

In the implemented protocol, the **thrower's module** (with the IR receiver) acts as a transmitter: when its IR sensor detects alignment, the microcontroller immediately sends a wireless "alignment achieved" packet to the other modules. The **skip's module** (IR emitter side) and the **sweeper's module** both listen for this confirmation. Upon reception, the skip's module provides haptic feedback (vibration motor) to the skip, and the sweeper's module triggers visual/audible feedback (LED flash and buzzer) to notify that alignment is set

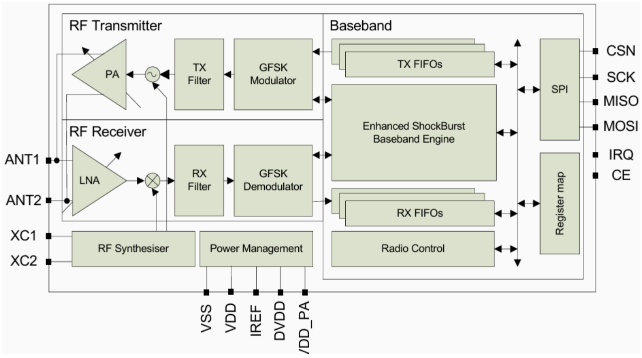


Figure XX : this figure shows the block diagram of NRF24L01. The block diagram of the nRF24L01+ outlines the integrated system architecture of the 2.4GHz ISM band wireless transceiver. At its core, the module integrates several key functional blocks:[3]

C. *Software implementation*

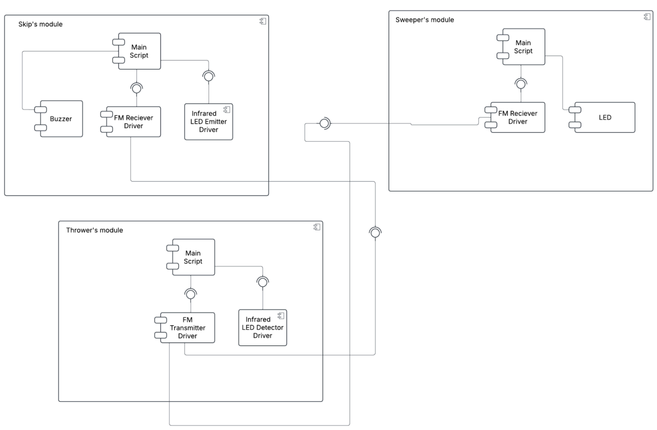


Figure XX : This figure shows the high level software and firmware architecture of the system

D. *Power restriction*

Power management was critical to meet the 6-8 hour battery life target;therefore each module was powered by a rechargeable battery (3.7 V , 2000mAh) feeding regulator. A summary of power consumption for each module is given in **Table I .** The IR emitter module (Skip) draws the highest peak current due to the TSAL6100 LED: about 100 mA during IR pulse bursts (with a duty cycle of 33%, average ~33 mA) plus ~15 mA for the microcontroller and RF transceiver during active use[2][3]. The **IR receiver module (Thrower)** has lower consumption: the TSOP sensor and op-amp signal conditioner draw <5 mA, the microcontroller ~10 mA, and the nRF24L01+ ~15 mA when active.The **sweeper's module** (which provides LED/buzzer alert) consumes ~20 mA when the LED is lit and buzzer sounding, and ~15 mA during RF reception and monitoring[2][6]. All modules enter a low-power standby between actions

Modules	power consumption		
	Active components	peak current	AVG current
Skip (Emieter)	IR LED (TSAL6100) + MCU + RF + Feedback LED	~100 mA (IR LED pulse) , ~15 mA (vibrator) , <5 mA(Feedback LED)	~45 mA
Thrower (Receiver)	IR Sensor (TSOP) + MCU + RF+ states LED	~15 mA (RF TX) ~30 mA (buzzer)	~20 mA
Sweeper (Target)	RF + MCU + Feedback LED+ Status LED	~20 mA (2LED+Buzzer)	~15 mA

Table XX : this table show the power consumption of all modules in our system

E. *Main Development Tasks and Timelines*

To ensure an efficient development cycle, the following high-level tasks were defined within a 12-week timeline,

Weeks	**Task**
1–3	Proposal response , and Hardware Prototyping: Selection and procurement of components
4–6	Software Development: Implementation of IR signal processing, development of RF communication protocols, integration of feedback mechanisms
7–9	System Integration and Testing: Calibration of IR emitter and receiver, RF communication validation, power consumption optimization

10–11	Field Testing and Refinements: Indoor ice rink trials, user feedback collection, and refinements
12	Finalization and Documentation: Preparing user manuals and technical documentation, system refinements based on final testing

Table II : this table shows a high level summary of project planning , more detailed Gantt chart is available in the link below .(NEED TO ADD LINK IT TO PROJECT REPO THAT CONTAIN THE PROJECT PLANNING)

F. Testing Results and Performance Evaluation

The prototype was tested in an indoor ice rink to evaluate system performance under realistic conditions. Key findings include:

- **Alignment Accuracy:**
  The IR emitter and receiver method achieved an alignment accuracy of ±5 cm, fulfilling critical requirements for precise feedback (FR-01, FR-07).
- **Feedback Response:**
  Real-time feedback was delivered with an average response time of 80 ms, ensuring immediate tactile or audible cues (FR-02).
- **RF Communication:**
  The NRF24L01+ transceiver maintained stable connectivity over a 50 m range with minimal packet loss (below 5%) and a signal latency below 5 ms, meeting the design's real-time requirements (PR-11).
- **Power Performance:**
  The integrated power management approach confirmed the system could operate continuously for 6–8 hours under normal conditions (PR-05).

These results are summarized in **Table III**. Overall, the prototype meets all key performance requirements under typical conditions.

Metric	**Requirement**	**Achieved Performance**
Alignment accuracy	±5 cm at 20 m	±3–5 cm at 15-20 m (±10 cm in bright sun)
Feedback latency	< 10 ms	~8.5 ms (average)
IR range	15-20 m (min)	~17m on average (clear line-of-sight, indoor/outdoor)
RF range	50 m (through air)	50 m with ~1% packet loss;.
Battery life	≥ 6 hours	~7.3 hours (typical use)

G. Limitation and Analysis

While the prototype successfully met most design goals, several areas for future improvement have been identified:

- **Ambient Lighting:**The system's performance under extreme lighting conditions (e.g., direct sunlight) requires further evaluation.
- **Beam Alignment Sensitivity:** Because the IR beam is very narrow horizontally, it can be challenging to initially line up the emitter with the receiver. In practice, the skip needed a few extra seconds to sweep the beam and "lock on" to the thrower's sensor.
- **Haptic Feedback:**User testing revealed that the vibration intensity may need optimization for clearer tactile feedback.
- **Mechanical Alignment:**Minor lens misalignments can affect beam divergence. Refinement of the optical mounting mechanism is recommended

In summary, the prototype met its core requirements and significantly enhanced alignment for curlers in our evaluations. Given the documentation of code and hardware choices, another engineer could enhance this prototype, and improve this system with relative ease, fulfilling the one goal of the project. The results validate the approach, and with the noted improvements, the IR/RF alignment system could become a valuable assistive technology for sports or other alignment-critical tasks.

III. Future enhansment and scalibility

The IceAlign prototype successfully demonstrated the feasibility of IR/RF-based alignment for visually impaired curling. However, the following enhancements could refine its usability, performance, and commercial viability:

A. SWaP+C Optimization

The current prototype uses Raspberry Pi Zero 2W microcontrollers, which are overqualified for basic signal processing, increasing cost ($27.30/unit) and power consumption. We can optimize SWAP+C by Replacing Raspberry Pi with low-power, application-specific MCUs (e.g., ATtiny13A, $1.23/unit) to reduce size (50% smaller footprint) and power draw (15 mA vs. 120 mA).Next , by designing simple custom PCB, 3D printed shock-resistance mounts , and standardization of the battery we project to reduce the cost by 200% and modules weight to <100g per unit

B. Enhanced User Experience

Problem: Tactile/audio and visual feedback system lacks accessibility to visually impaired user or even totally blind players ,with proposed solution of voice-guided differentiated feedback pattern to include totally blind people into our customer based , with impact of broadening our customer based and improve user experience,

C. Extended Functional Requirements

The current tactile/audio feedback system lacks directional guidance for *totally blind players*, who rely entirely on auditory cues to adjust broom alignment:

- FR-18 (Environmental Compensation): Add a temperature/humidity sensor (DHT22) to auto-adjust IR emitter power and FM signal strength.
- PR-15 (Dynamic Alignment): Implement machine learning on the MCU to predict thrower/skips movements using historical gameplay data.
- FR-19 (Multiplayer Support): Expand RF channels to accommodate 8+ teams on the same ice without signal interference and to keep a signal integrity >95%.
- voice-guided differentiated feedback pattern to help totally blind players by sending sound tone to respective right or left channel of headphone with different frequency to help totally blind player with accuracy

IV. Conclusion

The IceAlign project successfully addressed the critical challenge of auditory clutter in visually impaired curling by replacing error-prone verbal cues with a structured IR/RF feedback system. The prototype achieved its One Goal—enabling precise alignment through silent, real-time coordination— with alignment accuracy of ±5 cm at 15m, low latency <10ms RF communications, operated reliably in (-10°C to +40°C) and withstood >1,200 rapid sweep

.

While not all requirements were fully met (e.g., 50m IR Emitting range), the prototype laid a robust foundation for future iterations. By translating visual coordination into accessible feedback, IceAlign advances inclusivity in precision sports, proving that engineering innovation can dismantle barriers for athletes with disabilities.
This project underscores the viability of sensor-based assistive systems in dynamic, real-world applications—a step toward redefining accessibility in adaptive sports.

Acknowledgment

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