DEPARTMENT OF
Electrical and Computer Engineering

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

# Preliminary Design: IceAlign: Aligning Your Path to Success

## Revisions

| Revision | Author | Changes | Date |
|---|---|---|---|
| 001 | Sina Shaban | “initial release first version<br>” | 2025-02-08 |
| 002 | Sina Shaban | “PDD_update revise based on the PDD” | 2025-03-22 |

DEPARTMENT OF
Electrical and Computer Engineering

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

# Table of Contents

# Acronyms

| | |
|---|---|
| IR LED | Infrared LED |
| MID | Minimum Implementation Design |
| FRs | Functional Requirement |
| PRs | Performance Requirement |
| UART | Universal Asynchronous Receiver-Transmitter |
| ADC | Analog-to-Digital Converter |
| Op-amp | Operational Amplifier |
| MCU | Microcontroller Unit |

# References

1. Vishay Semiconductors, *"TSAL6100 High Power Infrared Emitting Diode."* [Online]. Available: https://www.vishay.com/docs/81009/tsal6100.pdf.

2. *"High Power 30MM Smooth Convex Lens 30mm Optical Glass Lens, LED Bulbs - Amazon Canada,"* Amazon.ca, 2025. [Online]. Available: https://www.amazon.ca/gp/product/B011LDOIUM/ref=ox_sc_act_title_2?smid=A2YDCCZ33LG0IZ&psc=.

3. Vishay Semiconductors, *"TSOP322.., TSOP324.., TSOP344.., TSOP348.. Vishay Semiconductors Datasheet Values Refer to PCN-OPT-1308-2024 IR Receiver Modules for Remote Control Systems."* [Online]. Available: https://www.vishay.com/docs/82489/tsop322.pdf. Accessed: Mar. 22, 2025.

4. Microchip Technology Inc., *"ATtiny13A Data Sheet,"* [Online]. Available: https://ww1.microchip.com/downloads/en/DeviceDoc/ATtiny13A-Data-Sheet-DS40002307A.pdf
5. "SYNCHRONOUS BOOST CONVERTER WITH 2A SWITCH," 2003. Available: https://cdn-shop.adafruit.com/datasheets/tps61090.pdf

# 1 Purpose

This document describes the preliminary design for the Curling assistant for visually impaired people (IceAlign).

# 2 Concept of Operation

The high-level operation of the  IceAlign is illustrated by the following user stories and use cases.

## 2.1 User Stories

1) User Story 1
   I am a Skip. I rotate my broom until it is aligned with the thrower's stone. When I am aligned, I immediately receive audio or tactile feedback. I am able to align with the thrower without needing verbal cues.
2) User Story 2
   I am a Thrower. I prepare to release the curling stone. The sweeper's broom has an LED, which is positioned 3 to 5 meters away and within my field of vision. I aim toward the LED and release the stone accurately toward the LED that corresponds to the final target.
3) User Story 3
   I am a Sweeper. I try to position my broom to block the aligned infrared(IR) LED between the skip and thrower. As I move the broom and it blocks the alignment between skip and thrower , the Light on my broom activates. The activated light is bright enough. The thrower, even if visually impaired knows exactly where to aim the stone.
4) User Story 4
   I am a User. The system operates continuously for 6–8 hours on a single charge, and it notifies me when it's running low . It withstands physical impacts and wet/icy conditions during gameplay. It remains reliable throughout the match without frequent maintenance.

## 2.2 Use Cases

In this section the use cases are identified and described below in table 2.2.1 - 2.2.7. The use case diagram is shown in fig 2.2.1 below.

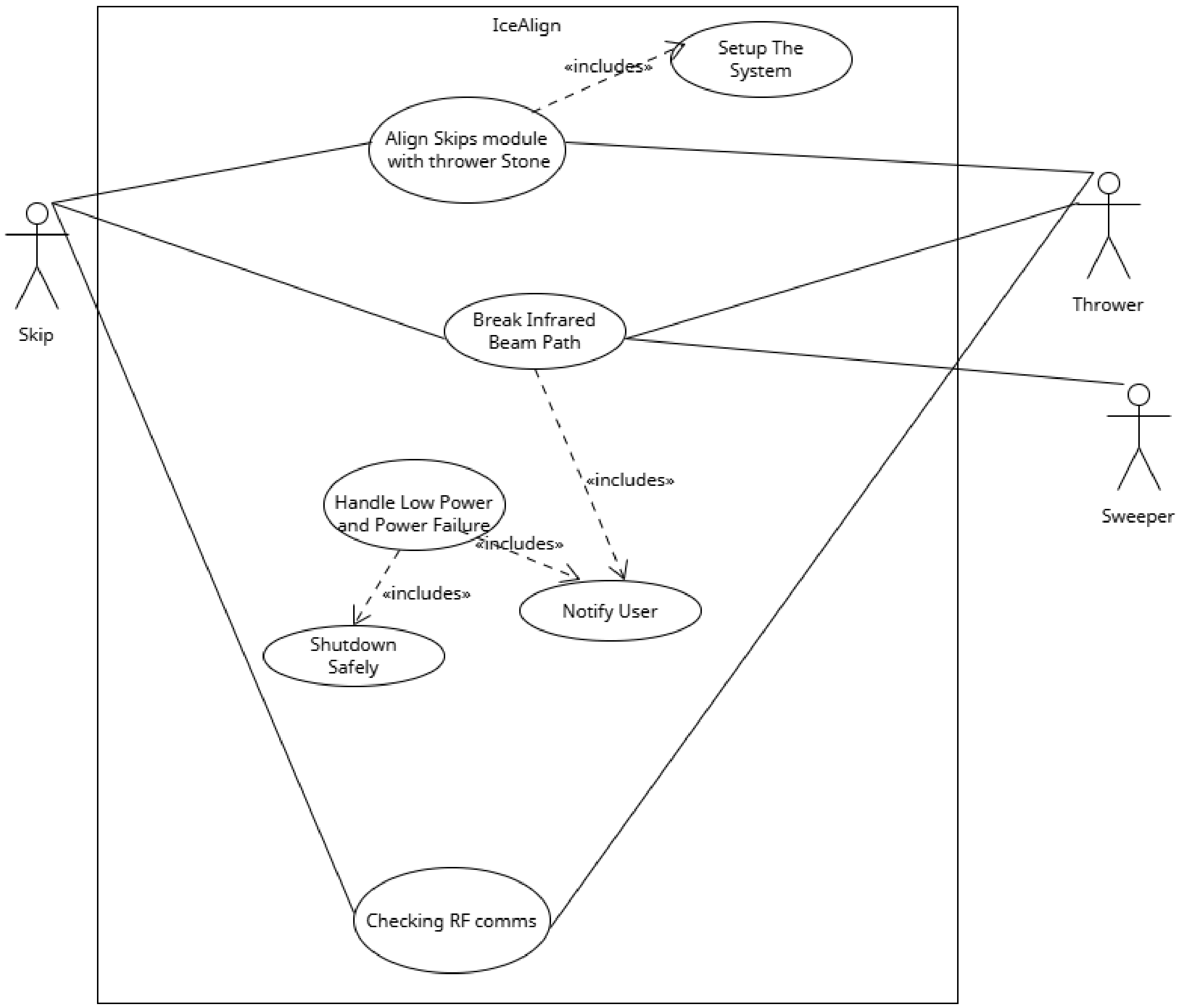


*Figure 2.2.1* Use Cases Diagram

DEPARTMENT OF
Electrical and Computer Engineering

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

*Table 2.2.1* Use Case – Aligning Skip and the thrower

| Use Case Description and Details | |
|---|---|
| **Number** | UC-001 |
| **Name (action)** | Aligning Skip and the thrower |
| **System** | IceAlign |
| **Actors** | 1. Thrower<br>2. Skip |
| **Use Case Goal** | To enable the skip to align their emitter module with the thrower accurately. |
| **Primary Actor** | skip |
| **Preconditions** | 1. The skip and thrower are in their respective positions.<br>2. The IceAlign system is properly set up. |
| **Postconditions** | 1. The skip's emitter module is accurately aligned with the thrower.<br>2. The thrower module is able to receive the beam from Skips module [1]<br>3. The skip receives confirmation of proper alignment.<br>4. Skip is able to keep the module mounted on their broom steadily. |
| **Basic flow** | 1. The skip turns on the emitter module mounted on their broom .<br>2. The emitter module sends an IR LED beam to the thrower's receiver module.[3]<br>3. The thrower's receiver module detects the IR LED beam and sends feedback to the skip's module.<br>4. The skip's module receives the feedback and provides alignment confirmation to the skip |
| **Alternate flows** | A. IR beam not detected<br>1. The skip turns his broom around but does not receive feedback on alignment<br>2. The skip retries the alignment by turning the broom<br>3. If the alignment is successful, the skip receives audio/tactile feedback |
| **Exceptions** | Possible exception includes:<br>1. Loss of power, batteries are discharged |

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

*Table 2.2.2* Use Case – Power Supply Failure

| Use Case Description and Details | |
|---|---|
| **Number** | UC-002 |
| **Name (action)** | Power Supply Failure/Battery Discharged |
| **System** | IceAlign |
| **Actors** | 1. Thrower<br>2. Skip<br>3. Sweeper |
| **Use Case Goal** | To handle power supply failure and regain power |
| **Primary Actor** | skip, thrower, sweeper |
| **Preconditions** | 1. The IceAlign system is in use and looses power<br>2. The IceAlign system does not power on |
| **Postconditions** | 1. The IceAlign system is safely shut down. |
| **Basic flow** | 1. The Ice Align system loses power<br>2. The IceAlign system detects the power supply failure and shuts down.<br>3. The users can see this by the power light turning off<br>4. The user replaces the batteries |
| **Alternate flows** | 1. Loose wiring:<br>a. When initiating battery replacement, if the user notices loose wiring, the user reinserts the power cables into the battery as well as the IceAlign module<br>2. Battery recharging:<br>a. the user recharges them using an external power source.<br>b. the user return to the game |
| **Exceptions** | |

*Table 2.2.3* Use Case – Breaking the IR Beam after alignment

| **Use Case Description and Details** | |
|---|---|
| **Number** | UC-003 |
| **Name (action)** | Breaking the IR Beam after alignment |
| **System** | IceAlign |
| **Actors** | 1. Sweeper<br>2. Skip<br>3. Thrower |
| **Use Case Goal** | Sweeper to accurately block the IR beam emitted by the skip's emitter module from reaching the thrower |
| **Primary Actor** | sweeper |
| **Preconditions** | 1. The IceAlign system is properly set up and calibrated.<br>2. The skip's emitter module is aligned with the thrower (UC-001).<br>3. The sweeper is in position to break the IR beam with his module turned on |
| **Postconditions** | 1. The IR beam is successfully blocked by the sweeper.<br>2. The sweeper's LED is activated, providing visual feedback |
| **Basic flow** | 1. The sweeper moves their broom into the path of the IR beam.<br>2. The IR beam is broken, triggering the sweeper's LED to activate.<br>3. The sweeper receives visual feedback from their LED, confirming the IR beam break. |
| **Alternate flows** | 1. The sweeper’s LED does not light up:<br>a.The Sweeper retries breaking the alignment<br>b.If successful upon retrying, the sweeper’s LED turns on |
| **Exceptions** | 1. The alignment does not break if the sweepers broom is parallel to the alignment between skip and thrower<br>2. The sweeper’s LED does not turn on due to the throwers module receiving IR reflected from another surface |

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

*Table 2.2.4* Use Case – Set up the system

| Use Case Description and Details | |
|---|---|
| **Number** | UC-004 |
| **Name (action)** | Turning on the system |
| **System** | IceAlign |
| **Actors** | 1. Thrower<br>2. Skip<br>3. Sweeper |
| **Use Case Goal** | To enable the curlers to power on their respective systems |
| **Primary Actor** | skip, sweeper, curler |
| **Preconditions** | 1. The skip, thrower and curler have their batteries charged |
| **Postconditions** | 1. The IceAlign modules of the skip, thrower and curler are powered on, with the power light turned on. |
| **Basic flow** | 1. The skip, curler and sweeper place their charged batteries into the battery holder<br>2. They plug in the power cable from battery to their respective Ice Align module<br>3. all user turns on the system |
| **Alternate flows** | 1. the system did not turns on<br>a. the user check the battery<br>b. the user change the battery<br>c. system turns on |
| **Exceptions** | 1. The batteries are discharged and hence the IceAlign system does not power on |

*Table 2.2.5* Use Case – Check RF communication

| Use Case Description and Details | |
|---|---|
| **Number** | UC-005 |
| **Name (action)** | Check RF communication |
| **System** | IceAlign |
| **Actors** | 1. Skip<br>2. Sweeper<br>3. Thrower |
| **Use Case Goal** | To ensure RF comms are operational |
| **Primary Actor** | Thrower, Skip |
| **Preconditions** | 1. The IceAlign system is turned on<br>2. The skip and the sweeper are close to each other. |
| **Postconditions** | 1. The users can confirm the IR emitters, IR receivers, FM transmitters and FM receivers are all working. |
| **Basic flow** | 1. The the thrower's module is placed right in front of the skip's module such that the IR detector is right in front of the IR emitter.<br>2. The skip's module gives visual/tactile feedback indicating alignment and confirming the RF comms are working. |
| **Alternate flows** | 1. The the thrower's module is placed right in front of the skip's module such that the IR detector is right in front of the IR emitter.<br>2. The skip's module does not give visual/tactile feedback indicating an issue with the RF communication, or with the IR receiver and IR emitter |
| **Exceptions** | RF communication may be interrupted in cases of high RF noise |

*Table 2.2.6* Use Case – Notify User

| Use Case Description and Details | |
|---|---|
| **Number** | UC-006 |
| **Name (action)** | Notify User |
| **System** | IceAlign |
| **Actors** | 1. Thrower<br>2. Skip<br>3. Sweeper |

| | |
|---|---|
| **Use Case Goal** | To notify user incase of power failure |
| **Primary Actor** | IceAlign |
| **Preconditions** | 1. The Ice Align system is in use<br>2. One or multiple Ice Align modules run out of power |
| **Postconditions** | 1. The affected module safely shuts down to prevent malfunction.<br>2. The user is notified via a blinking LED, indicating the low battery status. |
| **Basic flow** | 1. A module detects low battery levels.<br>2. The LED starts blinking to alert the corresponding user.<br>3. If power continues to drop, the module shuts down safely to prevent data loss or hardware damage. |
| **Alternate flows** | 1. If the battery stabilizes (e.g., due to external power input), the LED stops blinking and normal operation resumes. |
| **Exceptions** | If the LED indicator fails, a sudden loss of power may occur |

*Table 2.2.7* Use Case – Safe Shutdown

| **Use Case Description and Details** | |
|---|---|
| **Number** | UC-007 |
| **Name (action)** | Safe Shutdown |
| **System** | IceAlign |
| **Actors** | 1. Thrower<br>2. Skip<br>3. Sweeper |
| **Use Case Goal** | To safely shut down the IceAlign system to prevent hardware damage or data loss. |
| **Primary Actor** | skip, sweeper, curler |
| **Preconditions** | 1. The IceAlign system is powered on.<br>2. The system detects low battery or critical failure. |
| **Postconditions** | 1. The IceAlign system is safely powered off.<br>2. No data or hardware is damaged. |
| **Basic flow** | 1. The IceAlign system detects low battery or critical failure.<br>2. The system notifies the user with a blinking LED or audio signal. |

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

| | |
|---|---|
| | 3. The system initiates a controlled shutdown process.<br>4. The system powers off after confirming that all active processes have been terminated. |
| **Alternate flows** | 1. If the battery is replaced or recharged before the system shuts down, the system resumes normal operation. |
| **Exceptions** | 1. Power loss before the shutdown process is complete could result in data loss or hardware damage. |

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

# 3 Functional and Performance Requirements

In this section the function requirements (FRs) and Performance requirements (PRs) are identified and described below in table 3.1 and table 3.2.

*Table 3.1 Functional Requirements*

| FR # | Functional Requirement Description |
|---|---|
| **FR-01** | The system must emit a **vertical planar Infrared LED beam** from the skip's broom for alignment. |
| **FR-02** | system provide **immediate audio/tactile feedback** to the skip when aligned with the thrower's stone within 10 ms |
| **FR-03** | The system must activate a **bright LED** on the sweeper's broom when the Infrared beam is blocked. |
| **FR-04** | The system must operate within a **temperature range of -10°C to +40°C** |
| **FR-05** | The system must be **battery-powered** with a minimum runtime of 6–8 hours |
| **FR-06** | The system must withstand **rapid broom movements** and physical impacts during gameplay |
| **FR-07** | The system must use **eye-safe infrared wavelengths** (e.g., 940nm) with power levels below safety thresholds comply with IEC 62471 standards. |
| **FR-08** | The system must be **easy to use**, requiring minimal training for visually impaired players. |
| **FR-09** | The sweeper's LED must remain visible in bright curling ring condition. |
| **FR-10** | The system must allow the thrower to **aim accurately** toward the sweeper's activated LED. |
| **FR-11** | The system must maintain reliable communication between modules (Skip, Thrower, Sweeper) with automatic error recovery |
| **FR-12** | All modules must be securely mounted to withstand broom vibrations and impacts |
| **FR-13** | The system must provide low-battery alerts (audio/tactile) and activate power-saving mode at ≤20% battery |
| **FR-14** | Components must be waterproof to operate in icy/wet conditions. |
| **FR-15** | The thrower's module must confirm alignment accuracy (±5cm) with the sweeper's LED before sweepers block the infrared beam |
| **FR-16** | The system must use modular connectors for easy battery replacement/recharging. |
| **FR-17** | Feedback signals (audio/tactile) must be unique to avoid confusion (e.g., distinct tones for alignment vs. errors). |
| | |

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

*Table 3.2 Performance Requirements*

| PR # | Performance Requirement Description | Related FRs |
|---|---|---|
| **PR-01** | The IR beam must maintain alignment accuracy (±5cm) at a range of ≥50 meters | FR-01 |
| **PR-02** | The audio/tactile feedback for the skip must have a response time of <10ms from alignment detection to confirmation. | FR-02 |
| **PR-03** | The sweeper's LED must emit light with a brightness of >5000mcd and an audible buzzer at 85dB (±5dB) to ensure visibility | FR-03, FR-09 |
| **PR-04** | The system must maintain **stable operation** across the specified temperature range (-10°C to +40°C). | FR-04 |
| **PR-05** | The battery must provide **6–8 hours of continuous operation** under normal gameplay conditions. | FR-05 |
| **PR-06** | The system must withstand **> 1000 rapid sweeping motions** without damage | FR-06 |
| **PR-07** | The IR emitter must operate at **< 1W power** to ensure eye safety and comply with IEC62471 standards. | FR-07 |
| **PR-08** | The system must require **< 30 minutes of training** for visually impaired users to operate effectively | FR-08 |
| **PR-09** | The sweeper's LED must emit **audible feedback (e.g., beep)** in addition to visual feedback to ensure that sweeper knows that they had indeed block the IR beam | FR-09 , FR-03 |
| **PR-10** | The thrower must be able to **aim within ±5cm accuracy** toward the sweeper's LED. | FR-10,FR-03 |
| **PR-11** | FM communication between modules must achieve ≥95% signal integrity at 50m range, with automatic retries for lost packets. | FR-11 |
| **PR-12** | Low-battery alerts (audio/tactile) must activate at ≤20% capacity, extending runtime by 30% in power-saving mo | FR-13 |
| **PR-13** | All modules must pass waterproofing and earth drop tests | FR-14 |
| | | |

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

# 4 System Design

The Visually Impaired Curling Assistance System (IceAlign) comprises three main subsystems: the Thrower's Module, the Sweeper's Module, and the Skip's Module. These interconnected subsystems work together to provide accurate alignment assistance and real-time feedback to visually impaired curlers, enabling them to improve their game performance. The following sections outline the major nodes and components of each subsystem, including hardware, software, and firmware components, and their relationships

## 4.1 System Architecture

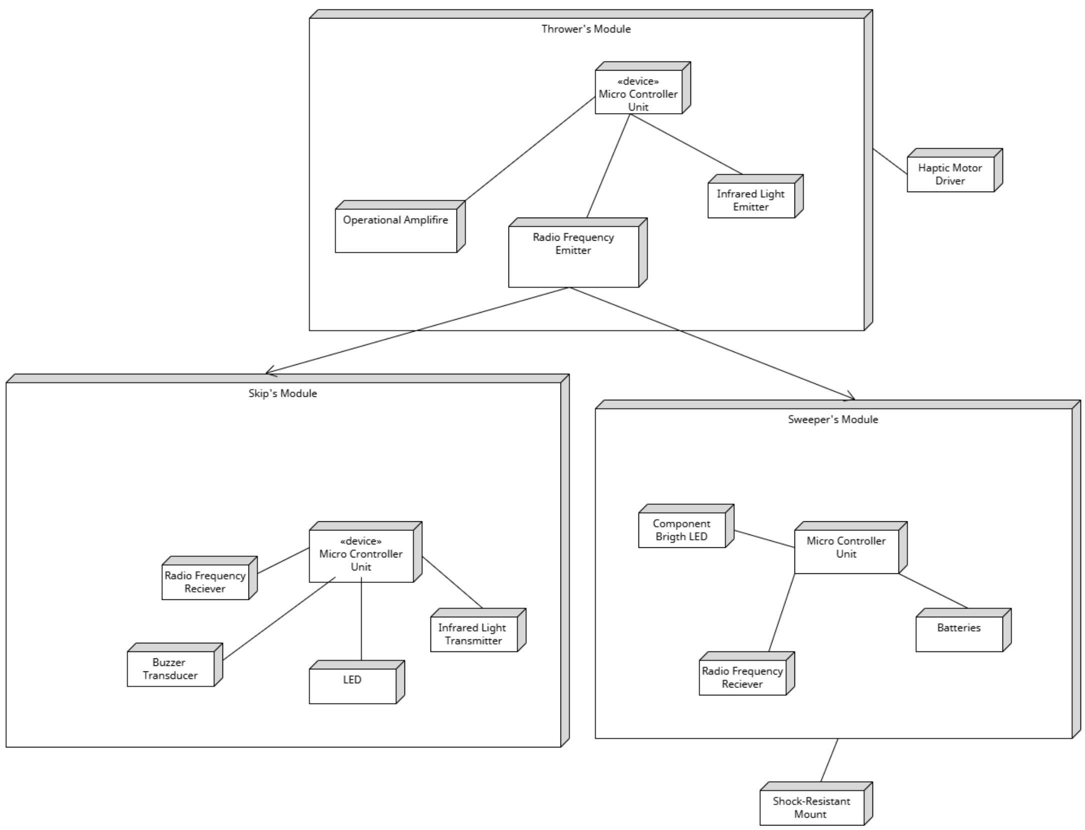


Figure 4.1.1 : This figure shows the major Hardware components. It's made of three main nodes that correspond to skip , thrower and sweepers modules.

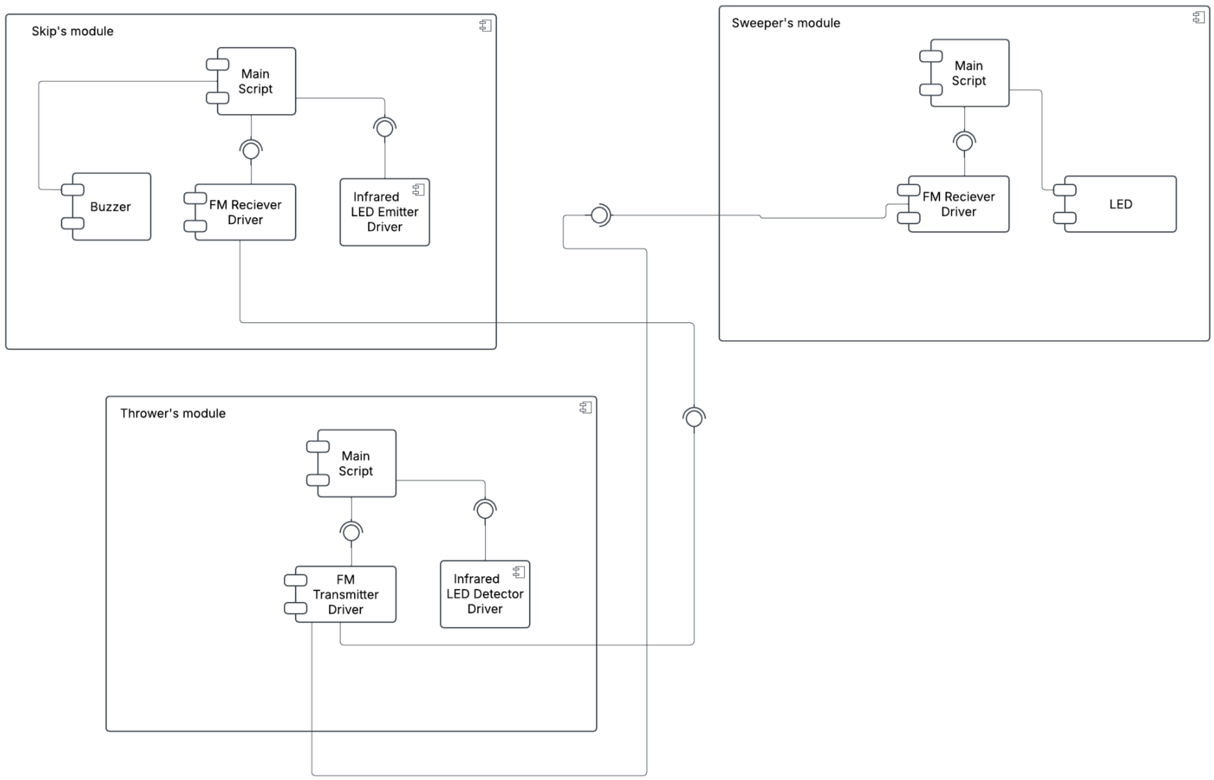


Figure 4.1.2 : This figure shows the high level software and firmware architecture of the system

### 4.1.1 Hardware Components

In This section , the hardware components are identified and described in below three tables 4.1.1.1 - 4.1.1.3.

*Table 4.1.1.1 Emitter module hardware components*

| CM # | Component | Description |
|---|---|---|
| CM -01 | IR LED (940nm) | TSAL6100 IR emitter; vertical planar beam (50m range, <1W power) |
| CM -02 | Microcontroller | Controls IR modulation and processes alignment confirmation signals |
| CM -03 | FM Receiver Module | 433MHz RF receiver ; receives alignment confirmation |

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

| | | |
|---|---|---|
| CM -04 | Battery | 3.7V Li-ion (2000mAh); powers Skip's module for 6–8 hours. |
| CM -05 | Vibration Motor | .5G vibration motor for tactile alignment feedback to Skip |

*Table 4.1.1.2 Receiver module hardware components*

| CM # | Component | Description |
|---|---|---|
| CM -01 | Photodiode | Detects the IR beam from the Emitter (e.g., TSOP3443). |
| CM -02 | Microcontroller | Processes photodiode signals and triggers FM transmission |
| CM -03 | FM Transmitter Module | 433MHz RF transmitter; sends alignment data to Skip/Sweeper |
| CM -04 | Battery | 3.7V Li-ion (2000mAh); powers Thrower's module |
| CM -05 | Signal Conditioning | LM318 Operational Amplifier (op-amp) + LPF/BPF filters; reduces noise in photodiode signals. |
| CM -06 | Buzzer | 85dB buzzer; provides audible alignment confirmation |

*Table 4.1.1.3 sweeper module hardware components*

| CM # | Component | Description |
|---|---|---|
| CM -01 | IR-Blocking Plate | Physically interrupts the IR beam to set the target position. |
| CM -02 | Microcontroller | Activates the LED upon receiving FM signals |

DEPARTMENT OF
Electrical and Computer Engineering

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

| | | |
|---|---|---|
| CM -03 | FM Receiver Module | 433MHz RF receiver receives activation signals |
| CM -04 | Battery | 3.7V Li-ion (1000mAh); powers Sweeper's module |
| CM -05 | LED + Buzzer | 5000mcd LED + 85dB buzzer; activated when IR beam is blocked. |
| CM -06 | Shock-Resistant Mount | Rubberized mount; withstands >1000 sweeps (1.5G force). |

### 4.1.2 Software/Firmware Components

In This section , the software/firmware components are identified and described in the below three tables 4.1.2.1 - 4.1.2.3.

*Table 4.1.2.1 Sweeper Module software and firmware components*

| CM # | Component | Description |
|---|---|---|
| CM -01 | Pi OS Lite | Runs Python python interpreter and allows us to interface with the GPIO ports of the Pi Zero 2W |
| CM -02 | Python script | Controls the LED and takes decisions based on the data from the FM receiver driver |
| CM -03 | FM Detector Driver | Processes and decodes the signal received and to extract the original data |

*Table 4.1.2.2 Skip module software and firmware components*

| CM # | Component | Description |
|---|---|---|
| CM -01 | Pi OS Lite | Runs Python python interpreter and allows us to interface with the GPIO ports of the Pi Zero 2W |

DEPARTMENT OF
Electrical and Computer Engineering

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

| | | |
|---|---|---|
| CM-02 | Python script | Controls the Infrared emitter to send pulsed infrared beams at a frequency o, controls the Buzzer/LED based on the data from the FM receiver driver |
| CM-03 | FM Detector Driver | Processes and decodes the signal received and to extract the original data |
| CM-04 | Infrared LED Emitter driver | Responsible to interface with the main script and control the Infrared LEDs |

*Table 4.1.2.3 Thrower module software and firmware components*

| CM # | Component | Description |
|---|---|---|
| **CM -01** | Pi OS Lite | Runs Python python interpreter and allows us to interface with the GPIO ports of the Pi Zero 2W |
| **CM -02** | Python script | Interfaces with the Infrared receiver driver and processes the data from the Infrared detection module. It also controls interfaces with the FM transmitter driver to send the alignment information to other modules |
| **CM -03** | FM Transmitter Driver | Receives the alignment information from the main script, encodes the information and transmits it |
| **CM -04** | Infrared Detector Driver | Receives the amplified analog infrared signal and passes digital alignment information to the main script |

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

# 5 System Requirements

The high level system requirements of our system IceAlign are identified and described in table 5.1 below.

*Table 5.1 System Requirements*

| SR # | System Requirement Desc | FR# | PR# | Notes |
|---|---|---|---|---|
| **SR-01** | IR LED emitting at 940nm wavelength with <1W power, compliant with IEC 62471 eye-safety standards. | FR-07 | PR-07 | Ensures eye safety and regulatory compliance. |
| **SR-02** | Microcontroller with low-power sleep mode. | FR-05 | PR-05 | Extends battery life to 6–8 hours |
| **SR-03** | FM Transmitter/Receiver modules using 433MHz band with ≥95% signal integrity at 50m range | FR-11 | PR-11 | Enables reliable alignment signaling between Skip, Thrower, and Sweeper |
| **SR-04** | Photodiode with 50m detection range. | FR-01 | PR-01, PR-10 | Detects IR beam and ensures precise thrower alignment. |
| **SR-05** | LED (5000mcd) paired with 85dB buzzer on sweeper | FR-09 | PR-03, PR-09 | Ensures visibility in bright/noisy environments. |
| **SR-06** | Vibration motor with 1.5G intensity for tactile alignment confirmation to the skip. | FR-02 | PR-02 | Provides immediate feedback (<10ms latency) for alignment accuracy. |
| **SR-07** | Li-ion battery (3.7V, 2000mAh) for all modules | FR-06 | PR-05 | Meets 6–8 hour runtime requirement, and activates power-saving mode at ≤20% capacity |
| **SR-08** | All components rated for stable operation at -10°C to +40°C and ≤90% humidity | FR-04 | PR-04 | Ensures reliability in curling environments |

| | | | | |
|---|---|---|---|---|
| **SR-09** | Durable mounts tested for >1000 sweep | FR-08 | PR-06 | Withstands gameplay wear-and-tear. |
| **SR-10** | Retroreflective mirror with >90% reflectivity | FR-07 | PR-07 | Break Ir LED beam from getting to receivers module |

# 6 Minimum Design

The Minimum Design, also known as the "walking skeleton," is a critical component of our design process. It represents the bare minimum functionality required to demonstrate the viability of our IceAlign system. In this section, we will outline the key features and functions that will be implemented in the first development iteration.

Our Minimum Design focuses on delivering a functional system that can demonstrate end-to-end alignment between the skip, thrower, and sweeper. The key features and functions that will be implemented include IR beam emission and detection, alignment confirmation, communication through RM/FM transmitter and receiver, and a basic user interface for a system with a range of about 10m. These features will be implemented using a combination of hardware and software components on a simple breadboard, including the skip's emitter module, thrower's receiver module, alignment confirmation system, and basic feedback system. For the minimum initial design (MID), we plan on using a wired DC power supply instead of batteries for the Minimum design.

*Table 6.1 minimum Initial Design*

| MID # | Functional Block | Key design Point | implementation detail | Contribution to End-to-End Functionality |
|---|---|---|---|---|
| **MID -01** | IR Emitter Module | - Emits a vertical IR beam at 940 nm .<br>- Provides the initial signal for alignment. | IR LED(TSAL 6210 ) with a dedicated driver circuit on the Skip's module | Initiates the alignment process by emitting the beam that triggers detection in downstream modules. |
| **MID -02** | IR receiver Module & | Detects the IR beam reliably. | IR receiver (e.g TSOP 3448 ) paired with LM318 | Receives and processes the IR signal, ensuring |

DEPARTMENT OF
Electrical and Computer Engineering

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

| | | | | |
|---|---|---|---|---|
| | Signal Conditioning | - Uses noise reduction for accurate signal capture. | op-amp and active filters | that the correct alignment data is captured for further processing. |
| **MID -03** | Communication Module | Provides wireless data transfer between modules using FM signals | FM transmitter (on the Thrower's module) and FM receiver (on the Skip's/Sweeper's modules) interfaced with the MCU | Bridges the sensor and processing stages by transmitting the alignment data, enabling the system to work as a unified whole. |
| **MID -04** | Microcontroller Unit (MCU) | Centralizes signal processing and system control | | Integrates inputs from the sensor and communication modules and triggers the user feedback |
| **MID -05** | User Feedback System | Provides immediate visual/audio/tactile feedback (target response < 100 ms). | Feedback devices mounted on the respective modules (e.g., high-brightness LED, buzzer, and/or vibration motor) activated by the MCU. | Notifies users (skip, thrower, or sweeper) of proper alignment, thereby completing the end-to-end demonstration of system functionality |

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

# 7.High-level Hardware Design

In this section we described the design of each module in detail in tables 7.1 - 7.3.

*Table 7.1: Skip's Module Hardware Design*

| HD # | Component | Connection | Function | Notes |
|---|---|---|---|---|
| **HD-01** | IR LED (940nm) + Driver | Controlled via General-Purpose Input/Output (GPIO) port from microprocessor | Emits IR beam for alignment | Ensures eye safety (<1W power) |
| **HD-02** | FM Receiver Module | Connected to Microcontroller Unit (MCU) via Serial Peripheral Interface (SPI) Or Universal Asynchronous Receiver-Transmitter (UART) | Receives alignment confirmation signals | Enables real-time feedback |
| **HD-03** | Buzzer / Vibration Motor | MCU digital output | Provides feedback to Skip | Ensures alignment confirmation |
| **HD-04** | Li-ion Battery (3.7V) + Regulator | Powers all components | Provides stable power supply | Ensures 6–8 hours of operation |

DEPARTMENT OF
Electrical and Computer Engineering
11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

## Table 7.2: Thrower's Module Hardware Design

| HD # | Component | Connection | Function | Notes |
|---|---|---|---|---|
| **HD-01** | Photodiode + LM318 Op-amp | Signal processed via active filters & MCU Analog-to-Digital Converter (ADC) | Detects IR beam and confirms alignment | Ensures ±5cm accuracy |
| **HD-02** | FM Receiver Module | Connected to MCU via SPI Or UART | Sends alignment signals to Skip/Sweeper | Enables communication |
| **HD-03** | Li-ion Battery (3.7V) + Regulator | Powers all components | Provides stable power supply | Ensures 6–8 hours of operation |

## Table 7.3: Sweeper's Module Hardware Design

| HD # | Component | Connection | Function | Notes |
|---|---|---|---|---|
| **HD-01** | High-brightness LED (5000mcd) & Buzzer (85dB) | MCU digital/PWM output | Provides visual & audio feedback | Ensures visibility in noisy conditions |
| **HD-02** | FM Receiver Module | Connected to MCU via SPI Or UART | Receives alignment signals | Enables communication |
| **HD-03** | Li-ion Battery (3.7V) + Regulator | Powers all components | Provides stable power supply | Ensures 6–8 hours of operation |
| **HD-04** | IR-blocking Plate | Passive physical component | Disrupts IR beam when alignment is achieved | Marks target position |

# 8. High-level Software/Firmware Design

## Sweeper Module

1. **Pi OS Lite (CM-01)**
    - Runs on the **Raspberry Pi Zero 2W**, providing a minimal **Linux environment** with GPIO support.
    - Enables execution of the Python script and communication with hardware interfaces.
2. **Python Script (CM-02)**
    - Handles **LED control** and **decision-making** based on the processed FM data.
    - Interfaces with the **FM Detector Driver** to receive data from the Skip module.
3. **FM Detector Driver (CM-03)**
    - **Receives and decodes** FM signals transmitted by the Thrower module.
    - Extracts **alignment data** and passes it to the Python script for processing.

## Skip Module

1. **Pi OS Lite (CM-01)**
    - Provides a **Python execution environment** and GPIO support for interfacing with IR emitters, LEDs, and buzzers.
2. **Python Script (CM-02)**
    - **Controls the IR emitter** to send pulsed beams at a specified frequency.
    - **Interprets FM signals** received via the **FM Detector Driver** and triggers LED/Buzzer alerts for guidance.
3. **FM Detector Driver (CM-03)**
    - Decodes FM transmissions received from the **Thrower module**, ensuring accurate data interpretation.
    - Sends extracted information to the **Python script** to adjust guidance signals accordingly.
4. **Infrared LED Emitter Driver (CM-04)**
    - **Controls the IR LED pulses**, ensuring **precise signal timing** for alignment guidance.
    - Works with the **Python script** to adjust the **pulse frequency** based on detected alignment.

## Thrower Module

1. **Pi OS Lite (CM-01)**
    - Provides the **base system** for running scripts and managing hardware peripherals.
2. **Python Script (CM-02)**
    - **Processes data** from the **Infrared Detector Driver** to determine alignment status.
    - **Interfaces with the FM Transmitter Driver** to send alignment information to the **Sweeper and Skip modules**.
3. **FM Transmitter Driver (CM-03)**
    - Encodes **alignment information** from the Python script and **transmits it wirelessly** via FM signals.

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

  - Ensures **signal integrity** and reliable communication with the **FM Detector Drivers** in the **Skip and Sweeper modules**.
4. **Infrared Detector Driver (CM-04)**
  - Converts **analog IR signals** into digital alignment data.
  - Sends processed data to the **Python script**, which determines whether the **thrower is properly aligned**.

# 9. Prototype Budget

*Table 9.1 System Budget (ROM)*

| Component | Mfr P/N | Mfr | Qty | Unit Price | Extended Price |
|---|---|---|---|---|---|
| Infrared (IR) Emitter 940nm | TSAL6100 | Vishay Semiconductor Opto Division | 5 | 0.54 | 2.7 |
| THRU-BEAM SENSOR 508MM | 2168 | Adafruit Industries LLC | 2 | 9.03 | 18.06 |
| RASPBERRY PI ZERO 2W | SC0721 | Raspberry Pi | 3 | 27.3 | 81.9 |
| 10F Microcontroller IC | PIC10F200-I/P | Microchip Technology | 1 | 1.23 | 1.23 |
| Transducer Buzzers | PS1240P02BT | TDK Corporation | 5 | 0.73 | 3.65 |
| Wireless Transceiver Module | NRF24L01 | 10Gtek | 1 | 13.99 | 13.99 |
| **Reflector Pane** | CAXUSD | CAXUSD | 1 | 8.98 | 8.98 |
| | | | | Total Cost | 130.47 |

# 10 Alpha System Design

The Alpha Design of IceAlign we used Incremental prototyping, and we separate the system into increments of “must do” , “should do” , “could do” and add one increment at a time, and each future refined overtime , with the goal of producing market-ready product, focusing of optimizing the size, weight, power consumption and cost(SWaP -C) ;therefore, enhancing usability for visually impaired curlers. While in prototype phase we were able to validate core functionality of our product such as IR beam alignment,communication between the modules using wifi and visual and haptic feedback mechanism , in our Alpha design we refine these elements and with one major change of moving toward RF transreceiver module for communication, and increase the range of the system to create a robust, user-centric solution.

Furthermore, the key improvements of our system is to replace a Raspberry Pi Zero 2W with a low power , cheap , program-specific microcontroller like ATTINY13A , as the Raspberry Pi is overkill in our system , all components like FM transceivers, IR modules and the MCU will be integrated into custom PCBs, minimizing the weight and increasing reliability in icy and wet condition. For the battery system we decide to use rechargeable batteries with battery life of about 750 - 1000 maH, and for now we used Na-ion batteries,but it can be changed to Li-ion batteries in future,these standardized batteries with modular connectors allows the product to switch to different battery type as needed. To improve user experience and usability enhancement we decide to consider some issues and characteristics as follows:

Characteristics:

- Background: motivation to learn , task familiarity , technological skills
- Physical: height and strength , hand and finger size(for installation of the module ), health , age and gender.

Issues:

- Users can not always express what they want , but they often know what they don't like.
- Users may not know possible , or what's technically and economically feasible.

Next manufacturability is addressed through modular design principles, simplifying assembly and scalability. Cost reduction was achieved through bulk sourcing and component, compact PCB design, eliminating redundancies and overseeing the production to other countries. This Alpha design ensures IceAlign meets regulatory requirements while laying the foundation for mass production targeting visually impaired curlers .Finally with highlighted SWaP-C improvement we were able to reduce cost 40% and create a product that's 30% smaller and 20% lighter then the original product.

## 10.1 System Architecture

In This section , the system architecture of the alpha design is shown below in fig 10.1.1 - 10.1.2.

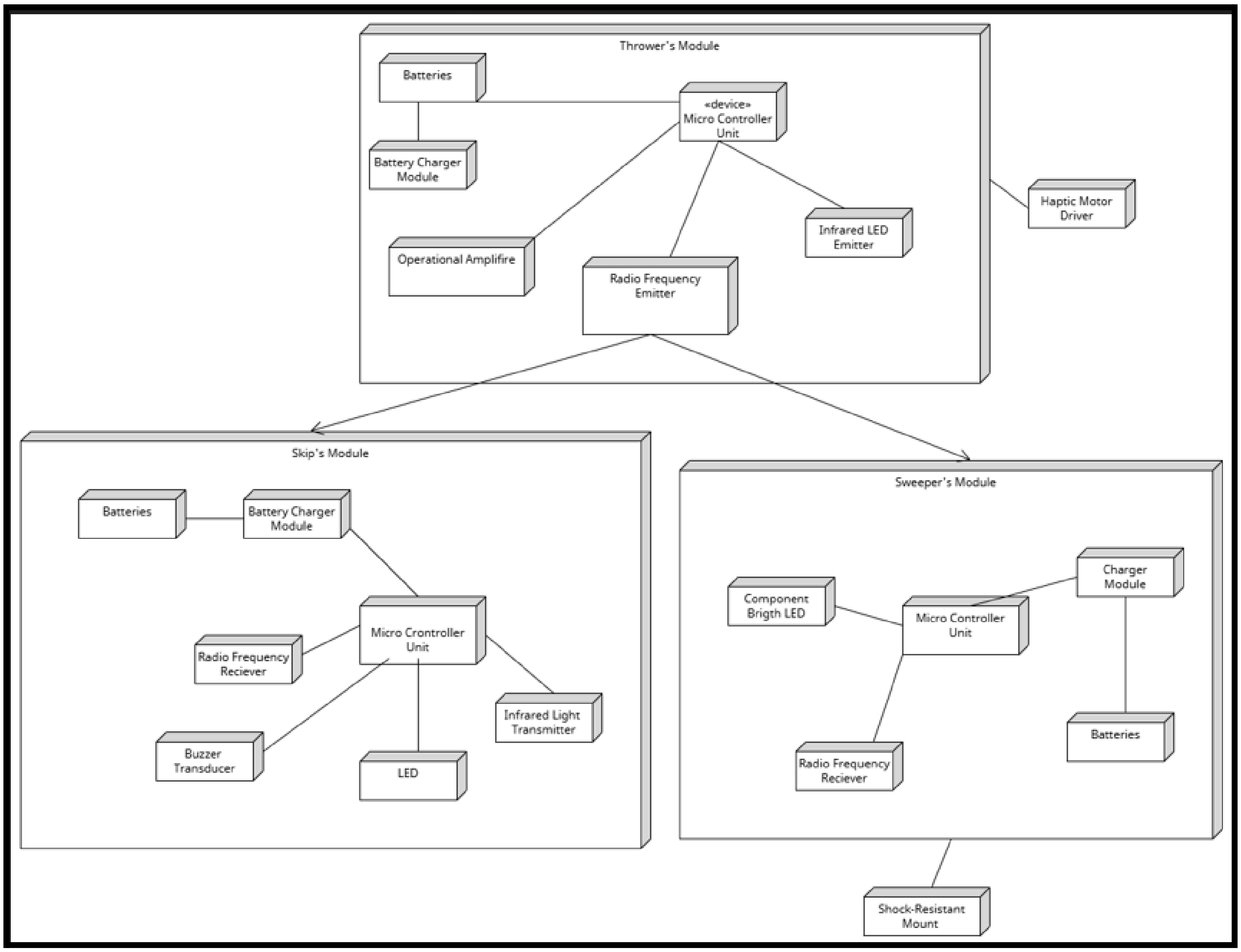


Figure 10.1.1 : This figure shows the major Hardware components. It's made of three main nodes that correspond to skip , thrower and sweepers modules.

DEPARTMENT OF
Electrical and Computer Engineering

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

**Software/FW design**

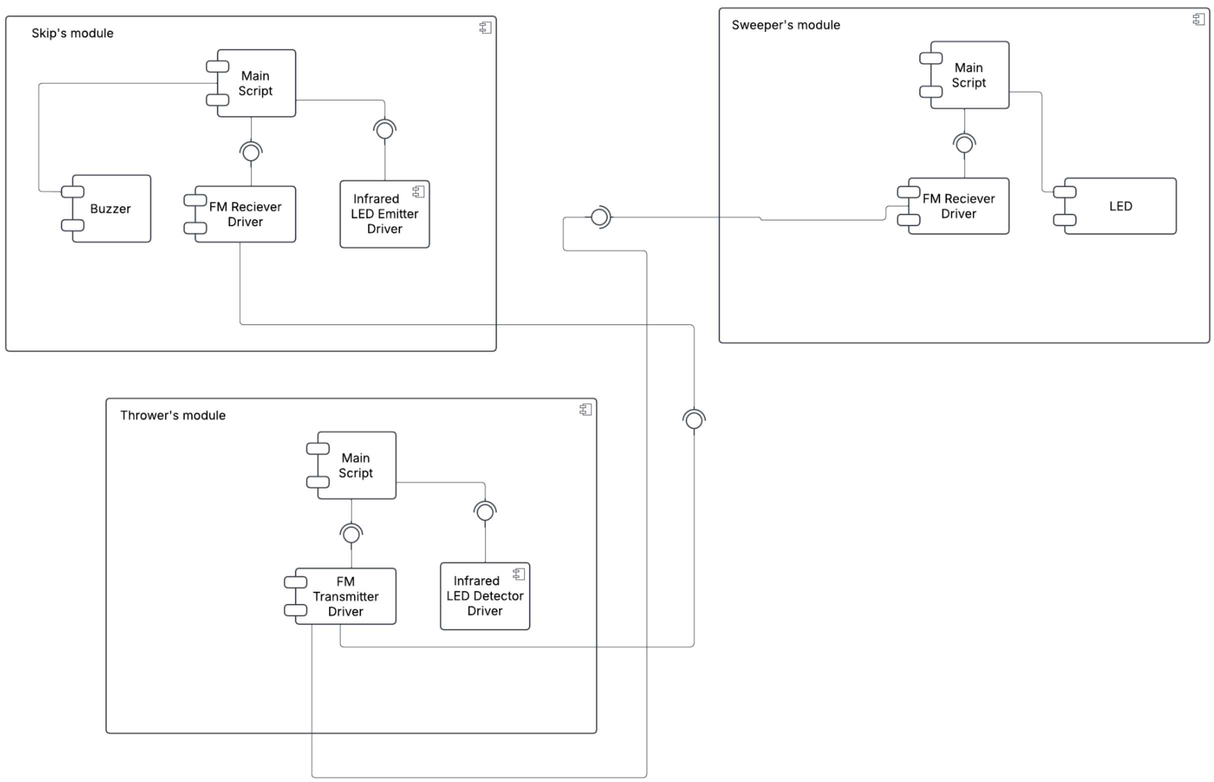


Figure 10.1.2 : This figure shows the high level software and firmware architecture of the system

# 10.2 Block Diagram

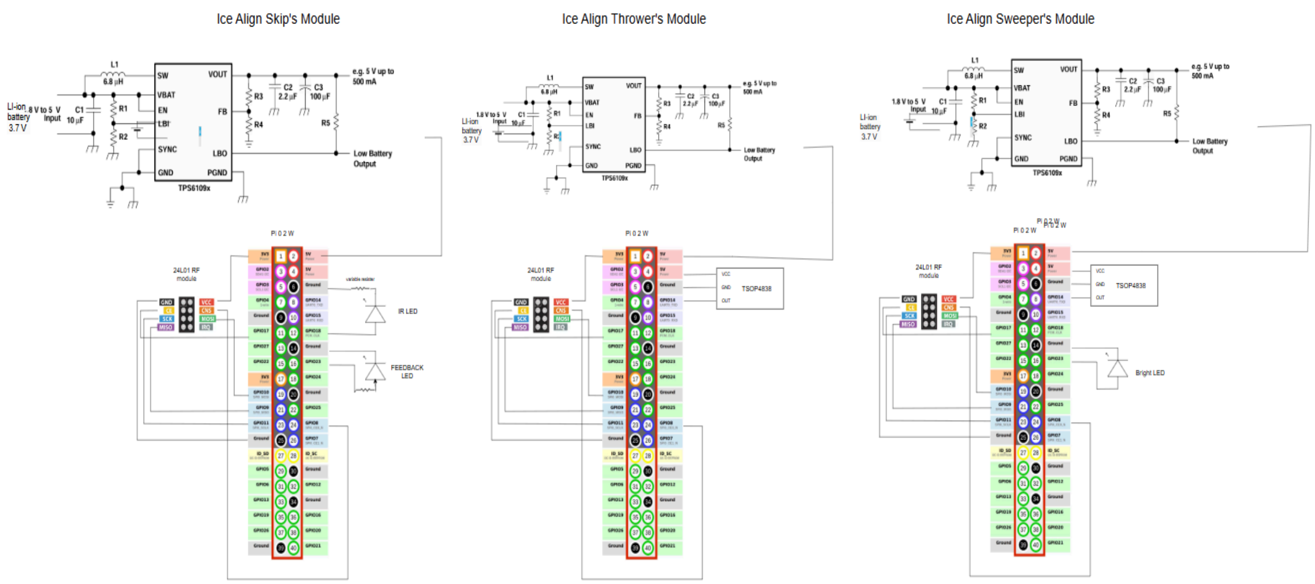


Figure 10.2.1 : this figure show the high level block diagram of all modules[5]

# 11 System Budget

DEPARTMENT OF
Electrical and Computer Engineering

11-203 Donadeo Innovation Centre for Engineering
9211-116 Street NW
University of Alberta
Edmonton, Alberta
Canada T6G 1H9

*Table 9.2 System Budget Updated*

| Description | Qty | Mfr PN | Vendor PN | Vendor | Unit cost | Ext Cost (1000) |
|---|---|---|---|---|---|---|
| IC microprocessor | 3 | ATTINY13A-PU | ATTINY13A-PU-ND | digitKey | 1.13 | 0.94 |
| RF transreceiver | 3 | nRF24L01 | NRF24L01-ND | digitKey | 1.95 | 1.95 |
| IR LED | 3 | SFH 4554-CWDW | 475-SFH4554-CWDW-ND | digitKey | 0.8 | 0.319 |
| LED Green/red clear | 4 | LTST-S115KRKGKT | 160-2232-1-ND | digikey | 0.15 | 0.00399 |
| IR receiver module | 3 | TSOP4838- | TSOP4838-ND | digitKey | 0.89 | 0.54 |
| powerBoost 500c | 3 | 1940 | B00PY2YTVU | Adafruit | 14.95 | 11.96 |
| Li-ion Battery | 3 | L37A26-1-0-2W | 3145-L37A26-1-0-2W-ND | digitKey | 11 | 10 |
| PCB | 3 | NA | NA | PCBWay | 2 | 0.5 |
| **Yield** | | | | | 100.00% | 95.00% |
| **Subtotal** | | | | | **98.76** | **26.21** |
| housing | 1 | NA | NA | icomold | 50 | 5 |
| packaging | 1 | NA | NA | TBD | 15 | 3.5 |
| Shipping | 1 | NA | NA | FedEx | 50 | 0.05 |
| return | 1 | NA | NA | NA | 0.00% | 5.00% |
| **Total** | | | | | 236.26 | 38.42 |

The total landed cost of the IceAlign system varies significantly depending on production volume, with economies of scale playing a critical role in reducing per-unit expenses. For a single unit, the cost is driven by high component prices and fixed expenses like housing and shipping, totaling approximately 213.7 CAD; however the cost reduced to just 34.76 CAD as a result of bulk discount for example the PCB drop to 25% of its original cost ,moreover the main driver of the cost is the battery rechargeable module with 34% of the cost and Li-ion battery with the 29% of the cost ,highlighting opportunities to negotiate with supplier and/or to find a similar product

Furthermore, scaling to 5000 or 10000 units would further reduce the cost with a reduction of another 20 and 30 percent respectively. This reduction stems from deeper bulk discounts. For Alpha product , managing the high-volume demand require strategic decisions:

- Target high-cost components
- Simplify housing design
- Automate assembly to reduce labor cost