Snooze-Cruiser

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1. Introduction

1.1 Problem and solution

Sleep inertia is a well-documented physiological phenomenon characterized by impaired cognitive and motor performance immediately after awakening. During this transitional state, individuals often experience grogginess, reduced alertness, and diminished decision-making capacity. A common behavioral consequence of sleep inertia is the instinctive silencing of alarms without fully regaining wakefulness, resulting in oversleeping and missed obligations. In academic, professional, and healthcare settings, repeated failure to wake on time can negatively impact productivity, academic performance, workplace reliability, and overall well-being.

Traditional alarm clocks and smartphone alarms rely almost exclusively on auditory stimuli. However, auditory alarms can be cognitively processed and dismissed while the user remains partially asleep. Although some commercial alternatives attempt to address this issue—such as puzzle-based alarms requiring cognitive tasks or mobile alarms that move away from the bedside—these solutions often present limitations. Puzzle-based alarms may be disabled through habituation or secondary device use, while flying or highly mobile devices can pose safety risks in confined spaces such as dorm rooms or small bedrooms. Furthermore, many existing systems lack robust obstacle avoidance or spatial awareness, making them unsuitable for real-world indoor environments.

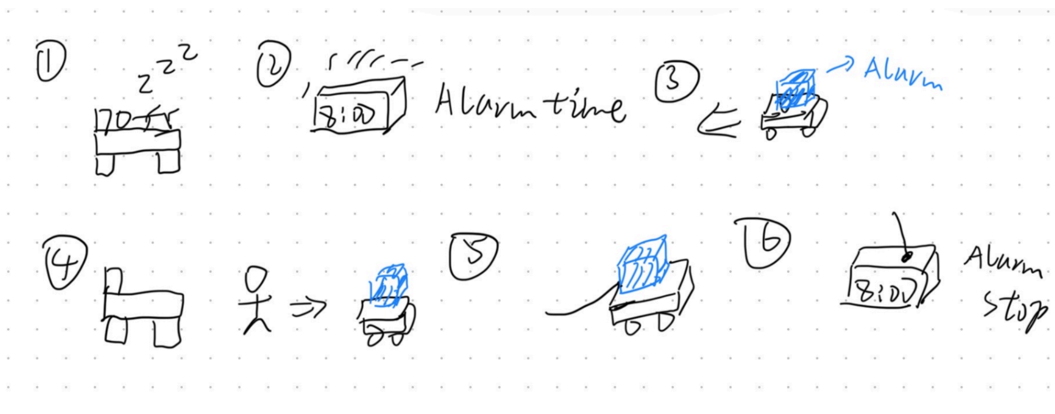
From a broader societal perspective, unreliable awakening systems affect public health and safety. Chronic sleep disruption and repeated oversleeping contribute to stress, absenteeism, and decreased performance. In safety-critical professions—such as healthcare, transportation, or industrial operations—delayed awakening may indirectly affect operational reliability. Economically, lateness and absenteeism reduce productivity and may carry cumulative institutional costs. Therefore, there exists a need for an alarm system that reliably induces full physical engagement while remaining safe, practical, and suitable for constrained indoor environments.

The fundamental limitation of current alarm systems is their failure to require meaningful physical activation to disable the alarm. An effective solution must compel the user to engage physically with the device in a manner that promotes full cognitive arousal.

We propose Snooze-Cruiser, a two-wheeled differential-drive robotic alarm system designed to physically move away from the user at the scheduled alarm time. Rather than relying solely on auditory stimulation, Snooze-Cruiser introduces a mobility-based engagement mechanism: when activated, the robot autonomously navigates the room, requiring the user to get out of bed and physically retrieve the device in order to silence it. This enforced physical interaction increases heart rate, motor activity, and environmental awareness, thereby reducing the likelihood of returning to sleep.

The system is designed for safe and reliable operation in confined indoor environments. Snooze-Cruiser employs onboard sensors for obstacle detection and avoidance, ensuring it can navigate around furniture and walls without causing damage. Odometry-based localization enables the robot to remain within a predefined operational boundary, preventing unintended escape from the intended area. Unlike traditional alarms that are disabled by pressing a button, Snooze-Cruiser deactivates only when inertial sensing detects that the robot has been lifted or securely grasped. This interaction criterion ensures deliberate physical engagement rather than passive dismissal.

1.2 Visual Aid



1.3 High-level requirements list

- The system shall reliably activate its alarm function at the programmed time within ±2 seconds, initiating both motion and audio output in a synchronized manner.

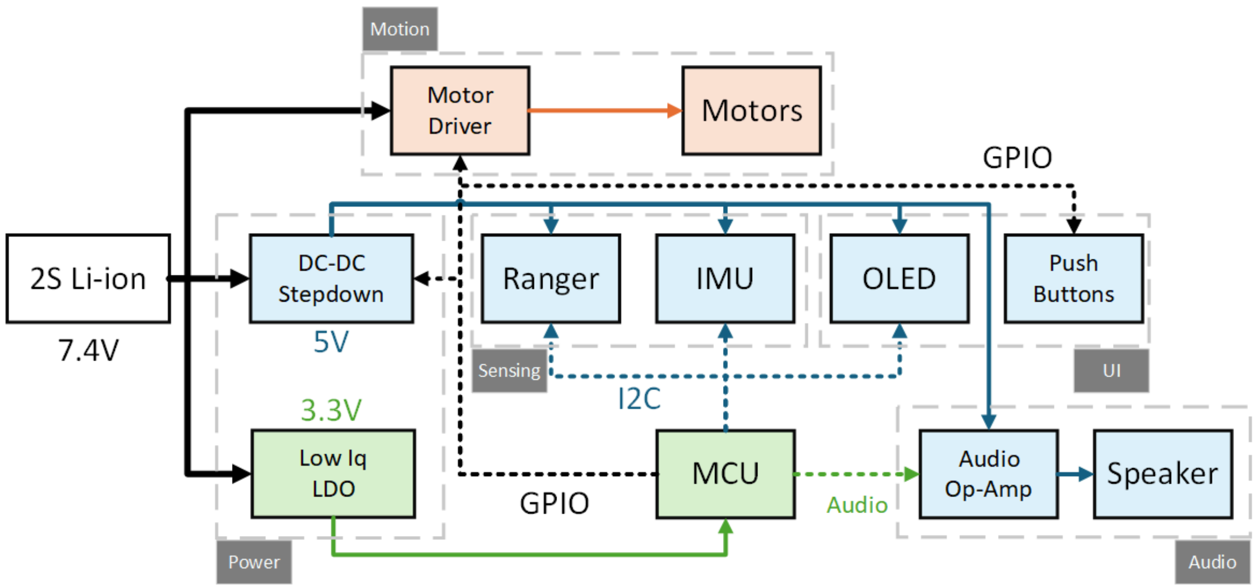
- The robot shall autonomously navigate an indoor environment for at least 2 minutes while avoiding obstacles and remaining within a predefined operational boundary.

- The system shall require physical user interaction to disable the alarm, using inertial sensing to detect when the robot has been lifted and stopping motion and audio within 1 second.

- The device shall operate safely in confined residential environments without causing damage to surroundings or posing risk to the user.

2. Design

2.1 Block Diagram



The Snooze-Cruiser system is organized around a central microcontroller unit (MCU), which coordinates sensing, motion control, user interface, audio output, and power management. The motion subsystem consists of a motor driver and DC motors that enable differential-drive locomotion. Environmental perception is provided by distance sensors (rangers) and an IMU, which communicate with the MCU via the I²C bus. The user interface includes an OLED display and push buttons connected through GPIO. The audio subsystem generates the alarm sound through an amplifier and speaker. Power is supplied by a 2-cell Li-ion battery and regulated to 5 V and 3.3 V rails. Together, these subsystems enable autonomous operation, obstacle avoidance, and pickup detection in accordance with the project's high-level requirements.

2.2 Physical Design

The Snooze-Cruiser is built on a two-wheel differential-drive chassis with a passive caster for stability. The custom PCB is mounted on the top surface of the chassis using standoffs to prevent electrical contact with the frame. Three Time-of-Flight distance sensors are positioned at the front-left, front-center, and front-right locations to provide forward obstacle detection coverage of approximately 180°. The IMU module is mounted near the center of mass to improve measurement accuracy for pickup detection. The OLED display and control buttons are placed on the top surface for user accessibility. The speaker is mounted on the side of the enclosure with ventilation openings to allow sufficient sound output. The battery pack is secured within the chassis to maintain a low center of gravity and prevent movement during operation.

The figure above shows the sketch of the relative positions of the three sensors, and the coverage of the sensors should be as shown.

2.3 Subsystems:

Motion subsystem:

The motion subsystem enables the alarm bot to move and evade obstacles when it is triggered. It consists of a motor driver integrated on the mainboard and DC gear motors on the purchased car chassis. The motors operate at approximately 5–7.4 V with a stall current of up to about 2 A per motor. The motor driver is controlled by the MCU via GPIO and PWM signals that determine direction and speed. Because the motors require higher current than the MCU can supply, the motor driver acts as a power interface between the control logic and the motors. The selected DRV8833 motor driver supports up to 2 A peak current per channel, making it suitable for driving the motors. This subsystem is responsible for the bot's dynamic behavior, enabling controlled motion within a confined indoor space at moderate speeds.

Sensing subsystem:

The sensing subsystem allows the alarm bot to perceive its surroundings and avoid collisions while moving. It includes three Time-of-Flight (ToF) distance sensors for obstacle detection.

These sensors are mounted at the front of the chassis (or on the mainboard with wiring to the front) to provide forward coverage. The VL53L1X ToF sensors provide distance measurements up to approximately 4 m with millimeter-level resolution. The sensors communicate with the MCU via the I²C bus at speeds up to 400 kHz. By continuously reading distance measurements, the MCU can determine whether an object is in front of the bot and adjust the direction of motion accordingly.

Gyroscope / IMU Subsystem:

The gyroscope, integrated within an IMU module, is used as a trigger to stop the alarm bot from operation. It measures linear acceleration and angular velocity along multiple axes, allowing the MCU to detect motion changes. Pickup detection is implemented by monitoring sudden changes in vertical acceleration and orientation, which indicate that the user has caught and lifted the car from a surface. When such conditions are detected, the MCU immediately stops the motors and audio output.

User Interface (Display and Buttons):

The UI subsystem provides a simple interface for setting and monitoring the alarm bot. It consists of an OLED screen and several push buttons mounted on the mainboard. The OLED communicates with the MCU via I²C, allowing status information such as the current time, alarm time, and system state to be displayed. The push buttons are connected through GPIO pins and allow the user to set and adjust the alarm time. Button inputs are debounced in software to prevent false triggering and ensure reliable operation.

Audio Subsystem:

The audio subsystem generates the loud sound used to wake the user. The MCU outputs a PWM-based audio signal, which is then filtered and amplified by a PAM8301 audio amplifier integrated circuit. The amplified signal drives the speaker. Because the speaker requires significantly more power than the MCU can supply, the amplifier is necessary to boost the signal amplitude. This subsystem provides the device’s primary alarm function and is designed to produce sound levels sufficient to wake a sleeping user.

Time Counting Subsystem:

Accurate timekeeping is required for the alarm bot. The system uses the internal clock of the STM32 microcontroller for timing functions, with the option to incorporate an external crystal oscillator if higher timing accuracy is required. Clock tolerance is an important feature for this system to ensure that the alarm activates at the correct programmed time.

Power Subsystem:

The power subsystem supplies all other subsystems with appropriate regulated voltages. A 2S Li-ion battery provides the primary energy source at approximately 7.4 V, and onboard regulators generate stable 5 V and 3.3 V rails. The MCU and sensors are powered by a low-noise 3.3 V supply, while higher-current devices such as motors and the audio amplifier operate from the battery or the 5 V rail. A Li-ion charging IC with protection circuitry is used to prevent over-charge, over-discharge, and short-circuit conditions. For some components, the power domains are gated by GPIO-controlled switches to reduce power consumption when idle. The subsystem is designed to provide sufficient current capacity for simultaneous motor operation and audio output while maintaining stable voltage levels.

2.4 Requirements and Verification:

1	Subsystem	Requirement (Quantitative + Tolerance + Conditions)	Verification Equipment	Verification Procedure (Step-by-step)	Recorded Results Format
2	System / Alarm Timing	R-SYS1: Alarm activates at programmed time within ±2 s over 10 trials, battery 6.4–8.4 V, 20–2	Stopwatch, video recording	Set alarm 2–3 min ahead; record actual trigger time; repeat 10 trials.	Table: trial #, programmed time, trigger time, error, pass/fail
3	System / Sync	R-SYS2: Motion and audio start within ≤100 ms in 9/10 trials.	Slow-motion video or oscilloscope	Capture both events; measure time difference; repeat 10 trials.	Table: trial #, Δt (ms), pass/fail
4	Motion	R-M1: Robot speed 0.20–0.60 m/s over 1 m on flat surface, battery 6.4–8.4 V.	Measuring tape, stopwatch	Mark 1 m path; time traversal; compute speed; repeat 5 trials.	Table: trial #, time, speed, pass/fail
5	Motion	R-M2: Autonomous operation ≥120 s without intervention on flat surface.	Stopwatch	Trigger alarm mode; observe continuous motion ≥120 s; repeat 3 trials.	Table: trial #, runtime, pass/fail
6	Motion / Driver	R-M3: Driver supports ≥2.0 A peak per motor for ≤0.5 s without failure.	Bench PSU, DMM/current probe	Induce start-from-stop events; verify functionality after test.	Pass/fail checklist
7	Sensing (ToF)	R-S1: Distance accuracy ≤ ±3 cm for 0.15–1.00 m under indoor lighting.	Measuring tape, serial monitor	Place target at known distances; log readings; compute error.	Table: true distance, measured, error, pass/fail
8	Obstacle Avoidance	R-S2: ≤1 collision per encounter; contact ≤1.0 s for 10 encounters.	Stopwatch, video	Place obstacle; trigger motion; observe collisions/contact time.	Table: encounter #, collisions, contact time, pass/fail
9	Boundary Control	R-S3: Stay within ~2 m × 2 m area; redirect within ≤5 s in 9/10 trials.	Measuring tape, stopwatch	Mark boundary; measure time to redirect after edge contact.	Table: trial #, redirect time, pass/fail
10	IMU Pickup	R-I1: Stop motion/audio within ≤1.0 s when lifted ≥2 cm in 9/10 trials.	Ruler, stopwatch	Lift robot ≥2 cm; measure stop time; repeat 10 trials.	Table: trial #, stop time, pass/fail
11	IMU False Trigger	R-I2: ≤1 false pickup in 20 trials during 120 s operation.	Stopwatch, log output	Run without lifting; log false detections; repeat 20 trials.	Table: trial #, false trigger Y/N, pass/fail
12	UI Buttons	R-U1: Response ≤200 ms; ≤1 false trigger per 20 presses.	Video, serial log	Press buttons 20 times; compare events vs presses.	Table: button, presses, events, pass/fail
13	UI Display	R-U2: Time and alarm status readable at ≥0.5 m.	Visual inspection	Power device; verify readability at 0.5 m.	Checklist + photo
14	Audio Output	R-A1: ≥70 dB(A) at 0.5 m for ≥30 s.	SPL meter or phone app	Measure sound level during alarm; verify duration.	Table: trial #, dB(A), duration, pass/fail
15	Audio Timing	R-A2: Audio starts ≤100 ms after trigger in 9/10 trials.	Oscilloscope or video	Measure delay between trigger and audio start.	Table: trial #, Δt (ms), pass/fail
16	Power 3.3 V	R-P1: 3.20–3.40 V for load ≤200 mA, input 6.4–8.4 V.	DMM, load, PSU	Apply loads; measure output voltage.	Table: load, voltage, pass/fail
17	Power 5 V	R-P2: 4.75–5.25 V for load ≤1.0 A, input 6.4–8.4 V.	DMM, load, PSU	Apply loads; measure output voltage.	Table: load, voltage, pass/fail
18	Battery Safety	R-P3: Battery temperature ≤45°C during 10 min operation.	IR thermometer, stopwatch	Run for 10 min; record temperature over time.	Table: time, temperature, pass/fail
19	Power Protection	R-P4: System shall tolerate input polarity reversal at 7.4 V for 10 s without permanent damage.	Bench PSU with current limit	Set PSU to 7.4 V with current limit ~0.5–1 A; connect battery input with reversed polarity for 10 s; disconnect; reconnect with correct polarity; verify normal boot and operation.	Pass/fail checklist + notes (current limit, observations)
20	System Environment	R-ENV1: System shall operate normally at 20–30 °C ambient temperature for ≥10 min.	Thermometer, stopwatch	Measure ambient temperature (20–30 °C); run alarm mode for ≥10 min; verify motion, sensing, audio, UI, and no unexpected resets.	Checklist + short run log (time, temp, pass/fail)
21	System Startup	R-BOOT1: System shall boot to ready state within ≤5 s after power-on in 9/10 trials (battery 6.4–8.4 V).	Stopwatch, video recording (optional)	Power-cycle device; measure time from power applied to 'ready' indication on OLED/LED; repeat 10 trials across battery range.	Table: trial #, V_batt, boot time (s), pass/fail
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2.5 Tolerance Analysis:

The most critical requirement for Snooze-Cruiser is reliable autonomous operation without unsafe behavior, including collision avoidance, stable motion control, reliable pickup detection, and accurate alarm timing. These functions depend on several hardware subsystems operating within acceptable tolerances. The following analysis evaluates whether component tolerances in key subsystems could cause failure of the system's primary requirements.

1. Motor Driver Current and Voltage Tolerance

The most critical requirement in the motion subsystem is ensuring that the motor driver can safely handle the motor's stall current. By Ohm's law, that

$I\_stall = V / R\_m$

For example, if the motor operates at 5 V and has a winding resistance of 2.5 ohms, then:

$I\_stall = 5 / 2.5 = 2$ A

Therefore, the motor driver must be rated at least 2 A, preferably with a 20–30% margin to tolerate the potential current spikes.

2. Distance Sensor Accuracy and Obstacle Detection Margin

The obstacle-avoidance system depends on the sensor's measurement tolerance and system response time. The distance sensor has an accuracy of ±2 cm, and if the programmed stopping threshold is 10 cm, the actual detection distance could range from 8 cm to 12 cm.

If the bot moves at velocity $v = 0.3$ m/s and the control delay is $t = 0.05$ s, then the stopping distance during the delay is going to be:
$d = 0.3 \times 0.05 = 0.015$ m = 1.5 cm

A larger safety margin (e.g., a 15 cm distance threshold) would be required in order to prevent collisions.

3. IMU Pickup Detection Threshold Tolerance

The IMU detects whether the bot is being lifted by monitoring changes in acceleration.

If the tolerance of the car has ±50 g tolerance, for example, and the detection threshold is set at about 100g, then the effective detection range becomes:

Minimum detectable = 100 − 50 = 50 g
Maximum detectable = 100 + 50 = 150 g

This would ensure that, in this case, the small vibration caused by no more than 100g tolerance will not be detected as the lifting caused by the user.

4. Audio Amplifier Output Power Tolerance

The audio subsystem must generate sufficient output power to drive the speaker. If the speaker impedance is 5 ohms and the amplifier peak output voltage is 5 V, then the RMS voltage is:

$$V_{RMS} = V_{peak} / \sqrt{2} = 5 / 1.414 \approx 3.54 \text{ V}$$

The output power is calculated as:

$$P = (V_{RMS})^2 / R = (3.54)^2 / 5 \approx 2.5 \text{ W}$$

If the supply voltage varies by ±10%, the power may range from approximately 2.25 W to 2.75 W to function ideally.

5. Clock Accuracy and Alarm Timing Error

Clock tolerance directly affects the accuracy of alarm timing. For the internal oscillator has ±1% frequency tolerance, then over 24 hours (86,400 seconds), the maximum timing error is:

$$\text{Timing error} = 0.01 \times 86400 = 864 \text{ seconds}$$

This means there could be about 864 seconds of error if the time counting is about 24 hours.

As for a 20 ppm crystal oscillator:

$$\text{Timing error} = 20 \times 10^{-6} \times 86400 \approx 1.7 \text{ seconds per day}$$

Even though the internal clock's timing error is not ideal, our design is not used in circumstances where the time exceeds 24 hours, so it won’t be a critical problem. Therefore, an external crystal oscillator is better, while both devices could work very well in general.

6. End

Based on the analyses above, all critical subsystems operate within acceptable tolerance margins for the intended indoor use environment. Adequate safety margins have been incorporated in motor driver capability, obstacle detection thresholds, pickup detection logic, audio output power, and timing accuracy. Therefore, the design is expected to function reliably under worst-case component tolerances.

3. Cost and Schedule

3.1 Cost analysis

Labor

Assume each team member is an entry-level Electrical and Computer Engineering graduate earning $42 per hour, which reflects typical starting salaries for hardware engineers.

Each member is estimated to contribute approximately 120 hours to the project.

Labor cost formula:

$Cost=(\$/hour)\times 2.5\times hours$

Cost per person:

$42\times 2.5\times 120=\$12,600$

For three team members:

$Total\ Labor\ Cost=3\times 12,600=\$37,800$

Parts

The following components are required to construct the Snooze-Cruiser prototype.

Core Electronics and Purchased Components

- SMD resistors and capacitors (various values) — ≤ $10
- Crystal oscillator (if needed) — ≤ $10
- Robot car chassis kit — $13
- OLED LCD display — $7
- STM32F446RCT6 microcontroller — $7
- Motor driver DRV8833 — $2.61

- Li-ion battery charger MCP73844 — $1.76
- Audio amplifier PAM8301AAF — $0.42
- Time-of-Flight sensor VL53L1X — $29.95
- N20 DC gear motors (2 pcs) — $25

Additional Required Components (Estimated)

These items are necessary for assembly but may not yet be purchased.

- Rechargeable Li-ion battery pack — ≈ $15
- Battery holder / protection circuit — ≈ $5
- Speaker — ≈ $5
- Wiring, connectors, headers, terminal blocks — ≈ $10
- Power regulation components (LDOs, inductors, etc.) — ≈ $10
- Switches and buttons for UI — ≈ $5
- LEDs and indicator components — ≈ $3
- Mechanical fasteners, standoffs, mounting hardware — ≈ $5
- Enclosure materials / 3D printing / fabrication — ≈ $15
- Miscellaneous prototyping supplies — ≈ $10

PCB and Manufacturing

- Custom PCB fabrication — ≈ $40
- Assembly materials (solder paste, stencil usage, etc.) — ≈ $10

Estimated Total Parts Cost

Total Parts Cost≈$244.74

Grand Total Project Cost
Total Cost=Labor+Parts=37,800+244.74≈$38,044.74

3.2 schedule

2/25 Delivering the first version design of PCB design to TA
3/2 - 3/4 Design Review with TA and instructor
3/9 - 3/11 Breadboard Demo - all ordering of parts and the design of the model should be done
3/23 Progress check for the project within the group
3/30 Individual progress report
4/6 - 4/8 Progress Demo
4/10 Team contract assessment
4/13 Final check before the Mock Demo
4/20 - 4/25 Mock Demo and Mock presentation
4/27 - 4/29 Final Demo
4/29 - 5/1 Final Presentation
5/6 Final Report
5/7 Lab check out and Lab notebook
Our team will meet weekly during the weekend to check the progress. Decisions will be made by voting.

4. Discussion

4.1 Societal Impact

The purpose of Snooze-Cruiser is to improve wake-up times through physical engagement, rather than auditory engagement. The consequences of delayed wake-up times can lead to poor academic performance, as well as reduced workplace reliability. The device can help mitigate these issues by encouraging physical activity when the alarm activates. This can help reduce instances of oversleeping, thereby having a positive effect on an individual's health.

The economic implications of wake-up devices are that they can improve punctuality and productivity in academic and work settings. The social implications are that it is designed for safe use in residential settings, such as dorms and apartments, thus reducing hazardous behaviors that can occur with uncontrolled moving devices. The environmental implications are that it uses rechargeable batteries, thus reducing battery disposal and energy consumption.

4.2 Engineering Standards

There are various professional and regulatory standards that are applicable to the project. The design is intended to comply with the IEEE Code of Ethics and the ACM Code of Ethics and Professional Conduct, which highlight responsible practice in engineering, awareness of risks, and concern for the welfare of the public [1], [2].

The design does not incorporate wireless communication. However, it does incorporate digital electronics that generate radio-frequency emissions. Therefore, it is intended to comply with the regulations set by the Federal Communications Commission (FCC) for unintentional radiators, as defined by 47 CFR Part 15 [3]. If wireless communication is incorporated into the design, pre-approved modules will be used for compliance with the FCC emission and interference limits.

The design follows safety practices for low-voltage, battery-powered consumer products.

4.3 Ethics

Engineers have a responsibility to ensure the public's safety and welfare. The IEEE Code of Ethics states that the safety, health, and welfare of the public shall be the engineers' highest priority in their professional activities; they must avoid actions that could harm people or damage their property (IEEE I.1, II.9) [1]. Similarly, the ACM Code of Ethics emphasizes that computing professionals must not perform actions that could cause harm, and they must conduct thorough evaluations of system risks and societal impacts (ACM 1.2, 2.5) [2].

In order to ensure the Snooze-Cruiser meets ethical standards, the design includes the following features that help ensure public safety and welfare:

- Speed and acceleration limits through firmware
- Automatic avoidance of obstacles through distance sensors
- Automatic shutdown of the motors when the device is lifted, indicating that it has been caught
- No cameras or microphones to protect user privacy
- Clear documentation of the limitations of the device and its conditions for use

4.4 Safety Considerations

Electrical Safety

The device uses a low-voltage rechargeable lithium battery pack. This reduces the risk of electrical shock. However, lithium batteries are associated with risks of overheating, short circuiting, and fires. There are various safety features that reduce the risks of battery failure and electrical shock to users and developers. These features are:

- A battery charger integrated circuit
- Current limiters and protection circuits
- Suitable power regulation
- Proper printed circuit board design
- Use of current limiting with bench-top switch-mode supplies during development

Mechanical Safety

Being a mobile device, it is prone to collision with people or other objects. Various design features reduce the risks of collision. These features are:

- Maximum speed limits
- Obstacle-detecting sensors
- Automatic shutdown of the motor when lifted
- Stability provided by the two-wheel design

Operating near staircases or raised surfaces is dangerous because of fall risks. Thus, the user manual will highlight safe environments for use, which will be limited to flat indoor surfaces.

Operational Misuse

Possible misuse includes modifying the firmware to make it operate faster, using it in hazardous environments, or placing it near edges or other obstacles. Mitigating strategies that could be employed include:

- Critical safety parameters made non-user-adjustable in the firmware
- Documentation of safe use conditions
- Demonstrations performed exclusively in indoor environments

Developer Safety

During development and construction of the project, safety guidelines will be followed by developers, including safe use of lithium batteries, safe soldering practices, avoidance of exposed wiring, and safe testing of motors. Where possible, testing of motors will be performed at reduced power settings to prevent unintended movement.

Additional Safety Considerations Identified During Development

During detailed design, other risks were identified that were not initially considered during development of the proposal, including:

- Increased speed of the motor at high battery charge levels
- Falling from elevated surfaces
- Unintended movement of the robot

Possible mitigating strategies that could be employed include:

- Firmware that limits speed irrespective of battery voltage
- Testing performed exclusively on flat surfaces
- Implementation of shutdown mechanisms
- Avoidance of operating the robot near stairs or edges during demonstrations

Citations

[1] IEEE, “IEEE Code of Ethics,” IEEE, Jun. 2020. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html

[2] Association for Computing Machinery, “ACM Code of Ethics and Professional Conduct,” ACM, 2018. [Online]. Available: https://www.acm.org/code-of-ethics

[3] Federal Communications Commission, “47 CFR Part 15 — Radio Frequency Devices,” Electronic Code of Federal Regulations. [Online]. Available: https://www.ecfr.gov/current/title-47/part-15