Design Document for a Solution to Faster Response Times For Aiding Seniors

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Needs Assessment

Customer Definition

Our primary clients are senior citizens in the city of Waterloo, who number about 18,710 people as of 2021 [1], as well as organizations and people who take care of these people. In Canada, a senior is generally defined as someone who has reached 65 years of age [2]. The average yearly income of a retired Canadian is $23,200 (from pension and other senior programs) [3]. Seniors, especially those above the age of 75, are prone to being injured, the most common injury being due to falling. Falls are the leading cause of injury-related hospitalizations and injury-related deaths among people aged 65 and older [4], with 6590 fall-related fatalities occurring in the Canadian 65+ population in 2021 [5]. These falls often result in chronic pain, a decreased quality of life, and increased caretaker responsibilities [4]. In order to mitigate the results of the fall, it would be ideal for the client to be able to immediately inform someone of their injury immediately after an injury, especially if they are isolated at the time of injury.

Competitive Landscape

1. Wearable Fall Detection Devices

Wearable devices, such as fall detection watches, are designed to alert caregivers or emergency services if a fall is detected. These devices often use accelerometers and gyroscopes to sense rapid changes in movement that may indicate a fall. Systems like

Apple Watch and Life Alert have popularized these technologies, offering instant emergency response.[6] Some shortcomings of these devices include: wearables require the user to wear them consistently, which some seniors may find uncomfortable, invasive, or may simply forget to wear. These devices can also either have false positives due to sudden movements unrelated to falls, or not detect a fall in certain scenarios; most devices detect only around 85% of falls. [6]

2. Home-Based Monitoring Systems

Non-wearable, sensor-based systems, like those that integrate with smart home technologies, offer passive monitoring. These devices include floor and wall sensors, or infrared cameras, that track motion and alert caregivers when they detect an abnormal event. Sensors integrated into smart home systems can monitor changes in movement and use AI to differentiate falls from daily activities[6][7]. While these systems are less intrusive, they are expensive: vendors such as Livindi have systems whose cost range from hundreds to thousands of dollars [7], which limits the availability of this option. It also is not feasible to implement these systems dependent if the layout of the house is too complex or does not have Wi-Fi. These monitoring systems also have been reported to make the elderly experience more loneliness, due to less human interaction[8].

3. Community-Based Exercise and Balance Programs

Exercise and balance programs, often offered by community health organizations, are preventative interventions that aim to strengthen seniors' physical stability, thereby reducing the risk of falls[9]. Safe exercise programs that are designed to improve strength and balance are the most effective fall prevention methods, directly lowering fall risk[10]. The shortcoming is that these programs are preventive but do not address immediate fall detection, so they may not assist in cases where a fall occurs unexpectedly. Access to these programs can also be limited by geographic and economic factors, making it difficult for all seniors to participate regularly.

Requirement Specification

Functional Requirements:

1. When the button on the client's device is pressed, the device sends a signal from the client's device to a nearby caretaker's device by wire to turn on a light on the caretaker's side. Signal to be relayed within 12 CPU cycles (0.166s) [11] with 3 seconds of margin to activate a red LED light on caretaker's device.
2. The client's device successfully sends an input to the caretaker's device with a range of 0-15 meters indoors[12].
3. After receiving signal, the red LED on caretaker's device should flicker on and off every 1hz for 1 minute [13].
4. If the caretaker's device receives the input successfully, the caretaker's device should send a signal back to the client's device to turn on a green LED within 5 seconds of the initial input signal by the sender [14].
5. After receiving signal, the green LED on the client's device should turn on continually for 1 minute as confirmation that the signal was successfully sent (1 minute to guarantee the client sees the light turn on) [13]

Technical Requirements:

1. To receive button signals, the GPIO pin is configured to handle button inputs [15]. The device will use a PA9 pin as the GPIO (General Purpose I/O) input pin receiving the button signals. The PA9 pin connects to a button which will be able to call for help by triggering an LED light on the caretaker's respective device.

2. The speed at which the devices can contact each other is dependent on the clock speed of the devices[16]. The devices' clock speed is to be set at a 72MHz frequency (the maximum CPU speed of this device) to receive signals constantly and continuously, and to minimize the latency as much as possible.

3. Must not consume, transfer, or discharge more than 30W of power at any point [18]. Must not store more than 500mJ of energy at any point [18].

Safety Requirements:

1. As undetected falls occur most often where the client is alone [4], such as a washroom, devices should be able to work properly under a certain wet environment to some extent. We are aiming for an Ingress Protection (IP) rating of at least IPx2[19].

2. Setting watchdog timer to monitor the device will prevent software from crashing and ensure that it is known definitively if device is currently operable or not [20]. The device should be equipped with fault detection systems, alarming users in some way if the device is defective in some way, most importantly whether the signal is sent to the caretaker and turns on the light on their device within 1 minute of sending the signal. If there was no indication of the device being broken, the caretaker might be tricked by the device into believing everything is fine regarding the client. Having a built-in self-test (BiST) into the device that runs routinely will decrease the likelihood of a defective device going unnoticed.

Analysis

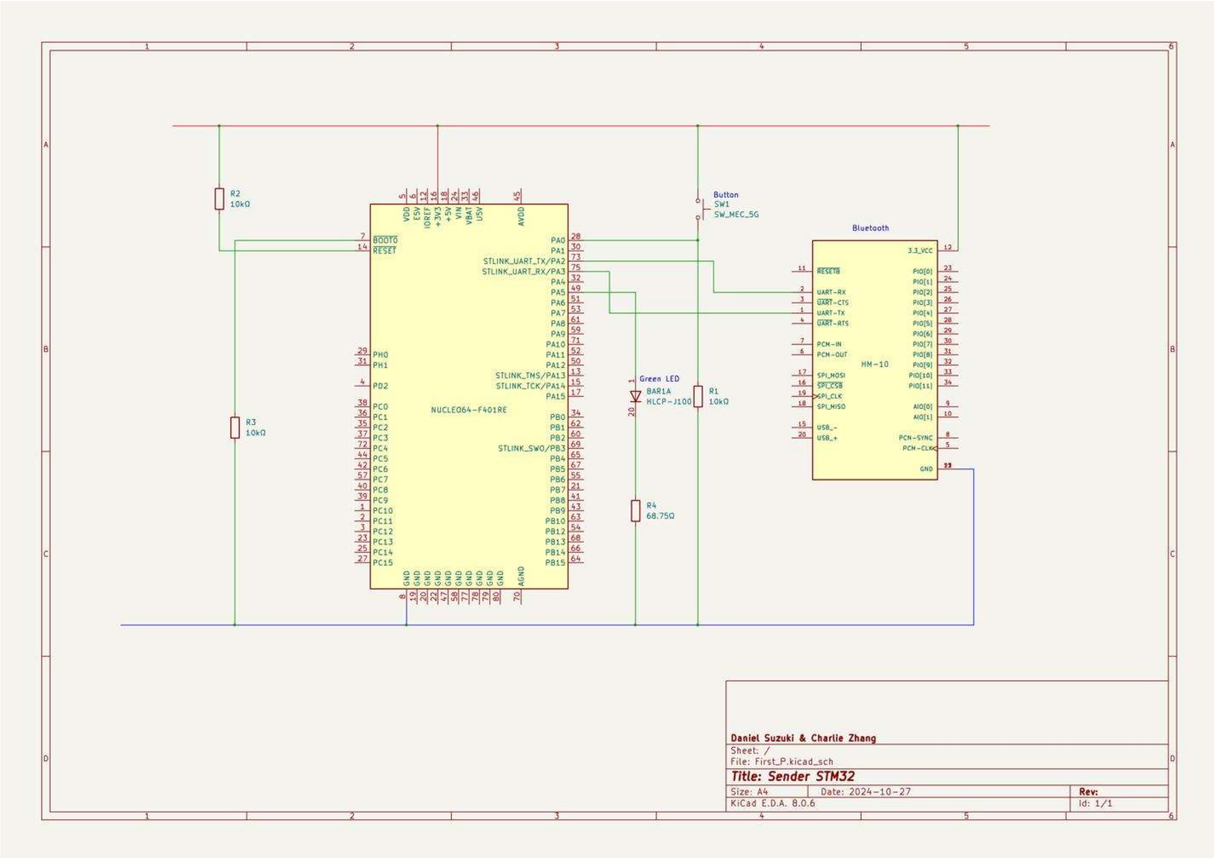
Design

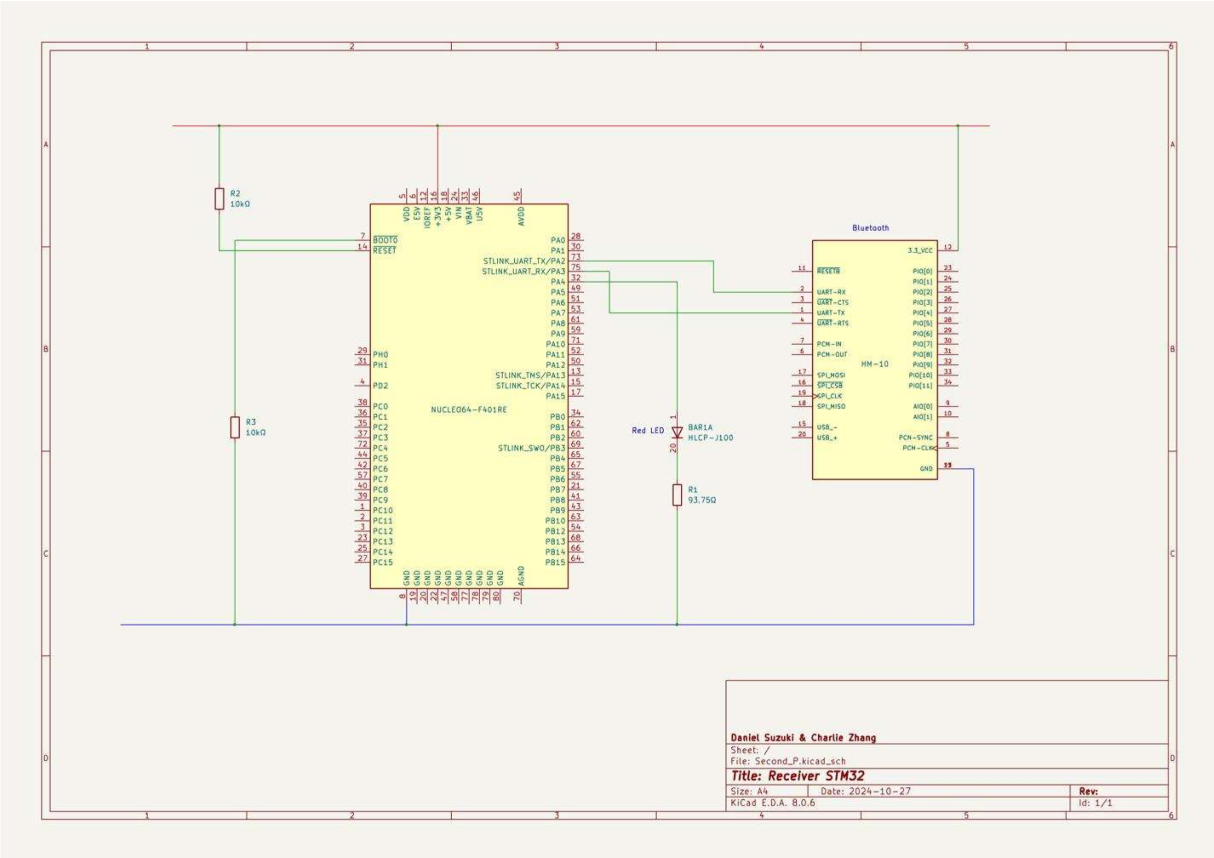
The design is primarily made up of 2 STM32 microcontrollers that are on two separate devices: a sender device and a receiver device. Each device operates on a 3.3V power supply[23] Connected to both microcontrollers is an HM-10, a Bluetooth Low Energy (BLE) module. The sender device has a green LED diode, and the receiver device has a red LED diode. There is a button (SW_MEC_5G) on the sender's device that allows the sender to transmit an input.

The sender and receiver STM32 microcontrollers are configured to transmit Bluetooth signals using the standard serial RX/TX protocol [21], allowing for two-way data exchange via Bluetooth. The device activates when the sender presses the button on their device, signaling a need for assistance. Upon pressing the button, the sender's microcontroller sends a Bluetooth signal to the receiver's STM32. Within 3 seconds, this triggers an alert, causing the red LED on the receiver device to flash at 1Hz for 1 minute.

Within 5 seconds of the initial signal, the receiver's STM32 sends a confirmation signal back to the sender's device. This activates the green LED on the sender device for 1 minute, confirming that the signal was successfully received. This setup enables reliable and timely requests for assistance in emergency situations, ensuring notifications are sent immediately to the receiver for prompt action.

(Schematics of the two devices below):





<u>Legend</u>
R—Resistor
GND— Ground
BOOT0–Used to select boot mode (The code program used)[23]
Reset —Used to restart the microcontroller[23]

The sender STM32 microcontroller operates in an infinite loop, continuously waiting for the emergency button to be pressed. When pressed, it immediately sends a Bluetooth signal to the receiver STM32 and then waits for confirmation. Once the receiver's signal for successful transmission is received, the green LED on the sender device lights up, indicating successful transmission. This standby loop ensures that the system remains ready to respond to emergencies, providing a reliable and continuous safety mechanism for seniors in need of assistance.

The receiver STM32 microcontroller also operates in an infinite loop, constantly monitoring for Bluetooth signals from the sender. When an emergency signal is detected, the receiver microcontroller activates the alert by flashing the red LED. It then sends a confirmation signal back to the sender. This continuous monitoring ensures the system is always ready to receive and respond to emergency signals, providing reliable, uninterrupted support for immediate assistance.

Alternate Design

One alternative design considered was for the receiver's STM32 microcontroller (MCU) to activate only a continuous visual alert, rather than a flashing alert. In this approach, when an emergency Bluetooth signal is received, the receiver MCU triggers the LED to stay on continuously rather than flashing, serving as a visual reminder for caretakers without being overly jarring. The MCU remains in an infinite loop, always ready to detect emergency signals and activate the light. This design offers a quieter, continuous monitoring system for senior safety.

The reason why the above design was ultimately forgone for the design with a flashing light was because it significantly increases the likelihood of the caretaker noticing the alert. Flashing lights draw more attention than constant luminescence, and the faster the flickering, the more attention is drawn to it [13]. 1Hz is around the frequency at which the eye is most sensitive to [13] and would cause less discomfort for the eyes than higher flashing frequencies. The enhanced visual reminder, achieved through flashing lights, ensures a more effective notification system, making it more suitable for emergency situations. This is why the flashing option was ultimately chosen: it offers a more reliable method for quickly drawing the caretaker's attention, ensuring prompt assistance.

Scientific Or Mathematical Principles/Technical Analysis

1. Ohm's Law: Ohm's Law is required to calculate the resistance necessary for powering the LEDs on each device without short-circuiting them. Ohm's law describes the relationship between voltage, current, and resistance, described by the equation $V = IR$ [22], where V is the voltage in volts, I is the current in amps, and R is the resistance in ohms. According to the datasheet for the STM32401RE, the

microcontrollers will supply 3.3 Volts [23]. The red LED has a forward voltage of 1.8V, and a forward current 16mA[24]. The green LED has a forward voltage of 2.2V, and a forward current 16mA[25]. Therefore:

The resistor of the red LED should have a resistance of $R = \frac{(3.3V - 1.8V)}{16mA} = 93.75\Omega$.

The resistor of the green LED should have a resistance of $R = \frac{(3.3V - 2.2V)}{16mA} = 68.75\Omega$.

2. Boolean Logic Algebra/Truth Values: Boolean Logic is required to determine when the device should send a signal from the sender's device to the receiver's device. The truth value of a statement is a determination as to whether a statement is true or false [26]. By evaluating truth values of conditions, such as whether the client has pressed the button and whether the system is ready, the device can decide when to activate the Bluetooth module and notify the caretaker. This logic ensures that signals are only sent when both conditions are true, providing reliable communication. An example of a Boolean equation that we will be using is $R = F(P, Q) = P \land Q$, where R is the result of action, P is the condition (i.e. whether the button is pressed), and Q is the system's readiness. When both conditions are met and the system is ready, the result of action is true (i.e. the call is made).

   For our device, a truth value on whether or not the client has submitted an input (pressed the button) has to be constantly evaluated. If the truth value is ever evaluated to be true, a signal will be sent to the other device via Bluetooth in order to turn on a light on the receiver's device. This would be a 1-input logic gate and must be implemented for the device to function. An example of an implementation of this principle in the device would be the following:

```
if (HAL_GPIO_ReadPin(GPIOA, GPIO_PIN_9) && system_Ready) {
    if (HAL_UART_Transmit(&huart1, (unsigned char *)&text, sizeof text, 100)) {
        Error_Handler();
    }
}
```

The above reads: When the button is pressed and the device is on, the sender's device sends a signal to the receiver's device. If the device fails to send a signal, throw an error. If it succeeds, the UART-TX port is activated and sends a signal to its Bluetooth module (HM-10), and then to the receiver's device to turn on the light.

3. **Kirchhoff's Voltage Law (KVL):** Kirchhoff's Law is required to ensure proper voltage and current distribution throughout the circuit. By using Kirchhoff's Voltage Law (KVL), we can verify that the sum of voltage drops across components in any closed loop equals the total supplied voltage. This ensures that each component, such as the Bluetooth module and microcontroller, receives the correct voltage for stable operation.

   KVL states that the sum of all voltages around any closed loop in a circuit is zero [27]. In other words, the total voltage gains and drops in a loop must balance out. This can be expressed as: $\Sigma V = 0$. [27]. KVL can be used to analyze the voltage distribution in circuits, ensuring that each component—such as the STM32, HM-10 module, and LED—receives the appropriate voltage. KVL is required to ensure that the HM-10 is operating within its recommended voltage range, which is 3.3V[28]. For example, using KVL, the voltage supplied to the HM-10 can be calculated by considering a section of the circuit:

   HM10—GND—Power Source

   (See schematic diagrams above).

   The equation for the circuit will be $V(HM-10) + 0V - 3.3V = 0$, therefore the voltage supplied to HM-10 is known to be 3.3V.

4. **Kirchhoff's Current Law (KCL):** KCL is required to ensure that the current flowing into any node in the circuit equals the current flowing out of that node. KCL states that the total current entering a junction (or node) is equal to the total current leaving it [27]. This is essential for maintaining balanced and stable current distribution among the various components, such as the microcontrollers (STM32s), the Bluetooth modules, and any connected resistors or LEDs. Mathematically, this is expressed as: $\Sigma I = 0$, or $I_{in} = I_{out}$ [27], where I represents the current at each point in the loop [27]. KCL can be used to determine the current through each branch connected to a junction, ensuring that the current drawn does not exceed safe levels for any component or power source.

For example, KCL must be used to make sure the LED has the same current as the resistor. When we use Ohm's law to calculate the current that flows into the resistor, which is 16mA (see Principle 1), we find a node before the resistor and confirm they have the same current, as $I_{in} = I_{out}$, thus we know the LED also has a current equal to 16mA, since the current at all points of the circuit is the same.

5. C++ Core Guidelines: C++ Core Guidelines are essential for programming the device as they provide a standardized approach to writing modern, efficient, and maintainable C++ code. The C++ Core Guidelines aim to "help developers adopt modern C++...and achieve a more uniform style across code bases" [29]. Adhering to these guidelines will enhance the readability, consistency, and maintainability of the code, making it easier for developers to understand and modify in the future.

   As the device's software will likely go through multiple revisions during the development process, having a clear and uniform coding style will be invaluable. It reduces the risk of errors, simplifies debugging, and enables multiple developers to work on the code collaboratively without compromising quality. By following C++ Core Guidelines, the development team can ensure that the code remains clean, modern, and aligned with best practices in C++ programming.

Manufacturing and Implementation Costs

Products	Quantity	Total Price ($)	Vendor	Vendor Location (Headquarters)	Manufacturer	Manufacturer Location (Headquarters)
HM-10 (Bluetooth device) [30]	2	21.14	Amazon	Seattle, Washington, United States [36]	DSD Tech	Shenzhen, China [39]
STM-32F401RE (Microcontroller) [31]	2	69.44	Amazon	Seattle, Washington, United States [36]	STMicroelectronics	Plan-les-Ouates, Geneva, Switzerland [40]

SW_MEC_5G (Button) [32]	1	3.95	Digikey	Chief River Falls, Minnesota, United States [37]	MEC Switches	Kitchener, Ontario, Canada [41]
10kΩ resistor [33]	5	1.75	Amazon	Seattle, Washington, United States [36]	E-projects	Edmonton, Alberta, Canada [42]
100 Ω resistor [34]	1	0.80	Amazon	Seattle, Washington, United States [36]	Huaban	Shenzhen, China [43]
75 Ω resistor [35]	1	0.80	Amazon	Seattle, Washington, United States [36]	Huaban	Shenzhen, China [43]
LED Basic Diodes [23][24]	2 (1red, 1green)	0.90	SparkFun Electronics	Niwot Colorado, United States [38]	China Young Sun LED Technology Company	Shenzhen, China [44]
Total		$98.78				

<u>Technologies Used</u>

This device uses the STM32CubeIDE from STMicroelectronics - headquartered in Plan-les-Ouates, Geneva, Switzerland.

Risks

Energy Analysis

According to the project requirements [18], the design must consume less than 30W of power and store less than 500mJ of energy at any time.

Based on the STM32F401RE datasheet [22], the maximum current for the STM32F401RE microcontroller is 100mA. Similarly, the HM-10 Bluetooth module has a maximum current of 8.5mA [28]. Each device includes an LED with a 300Ω pull-up resistor [45], drawing a maximum current of 16mA. Additionally, one path in the circuit has a 10kΩ pull-up resistor, limiting its maximum current to 7mA.

Thus, the total power consumption can be calculated as follows:

$$P = V \times I = 3.3V \times (100mA + 8.5mA + 16mA + 7mA) = 433.95mW$$

The STM32 microcontroller's maximum power consumption should not exceed 433.95mW at any time.

Since the design includes no batteries, capacitors, or other components intended for energy storage, any energy present in the system is minimal and dissipates almost immediately.

Therefore, our design remains within the project limits, consuming less than 30W and storing less than 500mJ of energy.

Risk Analysis

If used as intended, the device poses no direct safety risks to the user, as it operates with low voltage (3.3V) and is designed with minimal energy storage, reducing the likelihood of electric shock or overheating. If used in extreme conditions—such as high humidity, water exposure, or extreme temperature—the usability of the device as well as the safety cannot be guaranteed. In terms of environmental threats, if the source used to power the device is sourced from non-clean energy, such as burning fossil fuels, it may have a negative effect on the environment.

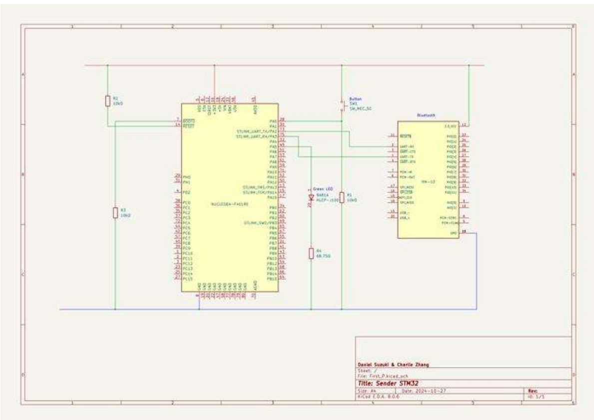
Using the device to communicate outside of the recommended range may result in the caretaker's device failing to receive the client's input. This may put the client at risk, as the client's caretaker may be under the false impression that the client is currently in good health.

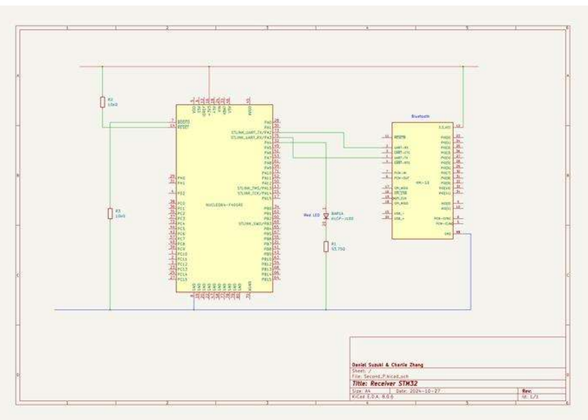
The device may be used more generally as a device that sends a signal when the client requires assistance of any kind, though this is outside of the intended purview of the device. If used this way, the client should communicate beforehand to their caretaker that it will be used this way. If they do not, the client risks the caretaker not treating a signal as urgent if used continually in such a way, risking a real emergency going unnoticed or untreated for longer than required.

The device could malfunction If the input sensor from the client's device fails to transmit to the caretaker's device, or if the LED light on the caretaker's side short-circuits or otherwise fails. If one of these two cases occurs, and the watchdog timer fails to detect it, there is potential for the client's signal failing to be sent to the caretaker's device. To ensure to the best of one's ability that a malfunction does not go unnoticed, the caretaker and client should regularly confirm the continued operation of the device.

Installation manual

(Refer to Design section above for full resolution schematics)





The product is made up of 2 devices: a transmitter (AKA sender) device, and a receiver device, labeled as such (see diagrams above). The product will arrive fully assembled; please do not alter any part of the product. The transmitter device is to be possessed by the user, the one who is at risk of bodily injury such as falling; the receiver device is to be possessed by someone close to the user, the caretaker. The device is intended to work only within a 20-meter range indoors. The device is intended to be portable.

User Guide

When the user has suffered an injury or otherwise required assistance, press the button on the transmitter device (see 'Sender STM32' diagram). The transmitter device will send a signal to the receiver device. Once the receiver device receives the signal, it will activate the red light on the receiver device, flashing for 1 minute, notifying the caretaker of the user's request for assistance. After the receiver device receives the signal, it will return a signal back to the transmitter device. Once the transmitter device receives the signal, it will emit a constant green light for 1 minute, indicating that the device successfully sent the signal to the receiver device.

Testing and Validation

Test Plan

For the purpose of testing, we will have a version of the device with a display screen on both the sender's and receiver's device that is not on the regular design. This version of the device will be programmed to record the time it sends and/or receives a signal. We will be testing the delay by adding a time log statement in both STM32 programs. We output the real time when the signal is sent from sender's device, and the real time when the LED pin is set on receiver's device.

1. When the button on the client's device is pressed, the device sends a signal from the client's device to a nearby caretaker's device by wire to turn on a light on the

caretaker's side. Signal to be relayed within 12 CPU cycles (0.166s) [11] with 3 seconds of margin to activate a red LED light on caretaker's device.

Test Setup: The sender device and receiver device are placed 15 meters away indoors. An input is sent to the sender device.

Environmental parameters: At room temperature (20-22 °C) [46], at standard atmosphere/air pressure (101.3kPa) [47], indoors.

Test input: The SW_MEC_5G switch (the button) on the sender device's circuits will be pressed (see the schematic), to give the sender device an input.

Quantifiable Measure Standard: The difference of the two times is to be displayed by each screen. The time when the input occurs is to be logged into sender device's screen. The time the receiver device receives the signal is to be logged into the receiver device's screen. The difference between these two times is the time it takes for the red LED to activate.

Pass Criteria: The difference between the sent time and receive time is less than 3 seconds.

2. The client's device successfully sends an input to the caretaker's device with a range up to 15 meters indoors [12].

We will be testing the maximum distance by placing two devices 15 meters away from each other indoors. If the transmission is successful at a distance of 15 meters, it will be successful for any distance less than that,

Test Setup: The sender device and receiver device are placed 15 meters away, indoors, the max recommended distance.

E**nvironmental parameters**: At room temperature (20-22 °C) [46], at standard atmosphere/air pressure (101.3kPa) [47], indoors.

Test input: The SW_MEC_5G switch (the button) on the sender device's circuits will be pressed (see the schematic), to give the sender device an input, which then prompts the device to send a signal to the receiver device to turn on the receiver device's red light.

Quantifiable Measure Standard: Whether or not the red LED on the receiver device flashes or not after the button on the sender's device is pressed.

Pass Criteria: The red LED on the receive device turns on, meaning that in the distance of 15 meters the send device can contact the receive device correctly.

3. After receiving signal, the red LED on caretaker's device should flicker on and off every 1hz for 1 minute [13].

We will be testing the hertz and duration of the red LED's flashing by connecting the red LED to an oscilloscope to measure the voltage change. We will check the duration of the red LED's flashing using a simple timer (i.e. phone timer)

Test Setup: The sender device and receiver device are to be placed 15 meters away indoors. An oscilloscope is to be connected to the receiver device.

E**nvironmental parameters**: At room temperature (20-22 °C) [46], at standard atmosphere/air pressure (101.3kPa) [47], indoors.

Test input: The SW_MEC_5G switch (the button) on the sender device will be pressed (see the schematic), to give the sender device an input.

Quantifiable Measure Standard: The red LED flashes on and off repeatedly for x seconds.

Pass Criteria: The red LED flashes on and off continuously for around 60 seconds [13].

4. If the caretaker's device receives the input successfully, the caretaker's device should send a signal back to the client's device to turn on a green LED within 5 seconds of the initial signal by the sender[14].

   We will be testing the sender device's feedback system by measuring the time it takes for the sender's green LED to activate by using the display on the sender's and receiver's device.

   Test Setup: The receiver and sender devices are to be placed 15 meters away indoors, the max recommended distance.

   E**nvironmental parameters**: At room temperature (20-22 °C) [46], at standard atmosphere/air pressure (101.3kPa) [47], indoors.

   Test input: The SW_MEC_5G switch (the button) on the Sender's device will be pressed.

   Quantifiable Measure Standard: Measure how many seconds after the button on the sender's device is pressed, the green LED turns on. This is done by having the display on the sender device record the time at which it sends the input, as well as the time it receives an output from the receiver device. The change in time is the time it takes.

   Pass Criteria: the green LED turns on within 5 seconds of the sender's device input.

5. After receiving signal, the green LED on the client's device should turn on continually for 1 minute as confirmation that the signal was successfully sent (1 minute to guarantee the client sees the light turn on) [13]

We will be testing the time the green LED is active for by starting a timer (i.e. phone timer) once the green LED on the receiver's device activates

Test Setup: The sender device and receiver device are to be placed 15 meters away indoors. Oscilloscope is connected to the Sender device to measure the voltage of the green LED.

E**nvironmental parameters**: At room temperature (20-22 °C) [46], at standard atmosphere/air pressure (101.3kPa) [47], indoors.

Test input: The SW_MEC_5G switch (the button) on the sender device's circuits will be pressed (see the schematic), to give the sender device an input.

Quantifiable Measure Standard: The green LED shining on for x seconds.

Pass Criteria: The green LED shines continuously for around 60 seconds [13].

6. The client's device successfully transmits a signal to the caretaker device through a wall within a 5 meters radius [12] within 3 seconds.

Test setup: The sender device and receiver device are to be placed 5 meters away indoors with a wall in between.

Environmental parameters: At room temperature (20-22 °C) [46], and standard atmosphere/air pressure (101.3 kPa) [47], indoors.

Test input: The SW_MEC_5G switch (the button) on the sender device's circuits will be pressed (see the schematic), to give the sender device an input.

Quantifiable Measure Standard:

The sender will record themselves pressing the button once the two devices are connected via Bluetooth. The time measured is to be the time from the button being pressed and the green LED light lighting up, as the green LED turning on is a sign that the receiver device received the signal and is flashing its red LED.

Pass Criteria:

The sender device's green LED must light up within 3 seconds of pressing the SW_MEC_5G button, confirming successful signal transmission through the wall.

Citations

[1] Canada, "Focusing on a selected geographic area, this product presents data highlights for each of the major releases of the 2021 Census. These data highlights are presented through text, tables and figures. A map image of the geographic area is also included in the product. The geographic levels presented in this product include Canada, provinces and territories, census metropolitan areas, census agglomerations, census divisions and census subdivisions.," *Statcan.gc.ca*, Jul. 13, 2022. https://www12.statcan.gc.ca/census-recensement/2021/as-sa/fogs-spg/page.cfm?topic=2&lang=E&dguid=2021A00053530016 (accessed Sep. 17, 2024).

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This document does not define danger, caution or safety other than the suggested meaning given in Table 1.

Experts should classify the status of hazard into danger, caution or safe.

Table 1 — Colour codes

Colour	Associated meaning	Proposed action
Red	Danger	Take appropriate safety action immediately
Yellow	Caution	Prepare to take appropriate safety action
Green	Safe	No action required

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