DESIGN DOCUMENT

Parth Vohra

Ronit Taleti

Client/Customer Definition:

The intended customers for this product are **senior Canadians (ages 65+) at risk of a fall-related injury, living in the city of Waterloo Ontario**. According to [14], **19.0%** of the Canadian population is **aged 65 or older.** [1] States that **20-30%** of seniors in Canada experience **1+** falls each year. The population of the city of Waterloo is **147,520** (including students and temporary residents) [2]. This would leave the total number of individuals considered as part of our client to be approximately **5,607-8,408**.

Studies show that fallen elderly with **long waiting times** on the ground before receiving help for a fall is associated with an **increase in mortality rates** [18]. A **quick response** can be very important when a senior is injured and **unable to call for help themselves**. Seniors with substantial injuries that require **immediate attention** can be forced to wait due to a lack of **immediate help**. The product we are creating addresses that issue by providing a tool that helps customers alert those around them and receive **immediate help**. The device will be wearable with an accelerometer and a gyroscope attached to determine whether the customer has fallen or not. If a fall has been detected, the device will trigger an alarm, alerting those around the customer of a sudden fall. This would improve the life of the customer as it would allow them to **receive help faster** and it would allow the customer to have more **independence** and **privacy** rather than having someone directly watch over them.

Competitive Landscape:

- Apple Watch [25]
  - The Apple Watch has its own fall detection system. It uses an accelerometer and a gyroscope similar to our own to detect changes in acceleration. Using this data they can detect if a fall has occurred.
  - The Apple watch is placed on the wrist and recorded movements are not necessarily going to be correlated with the activity of the rest of the body. A fall detection system merely based on the measurements captured by a smartwatch may be prone to false alarms due to the jerky nature of arm movement.
- SOS Mobile [26]
  - SOS Mobile is a product by Bay Alarm Medical that is used as a quick way for the elderly to get help in the event of an emergency. If an emergency occurs, the user just has to press the button in the middle and they will be connected to medical professionals.
  - The device can be worn around the neck allowing for improved plane detection. The device also uses a gyroscope and accelerometer. A GPS device is fitted to keep track of user location.
  - The device has 24/7 location tracking which can be seen as invasive to the user. The button on the device is prone to misclicks and false alarms.
- Homesafe Fall Detection [27]
  - The Homesafe fall detection device is used as a quick way for the elderly to get help in the event of an emergency. If the device detects that there is a fall, the user is immediately connected to emergency services.

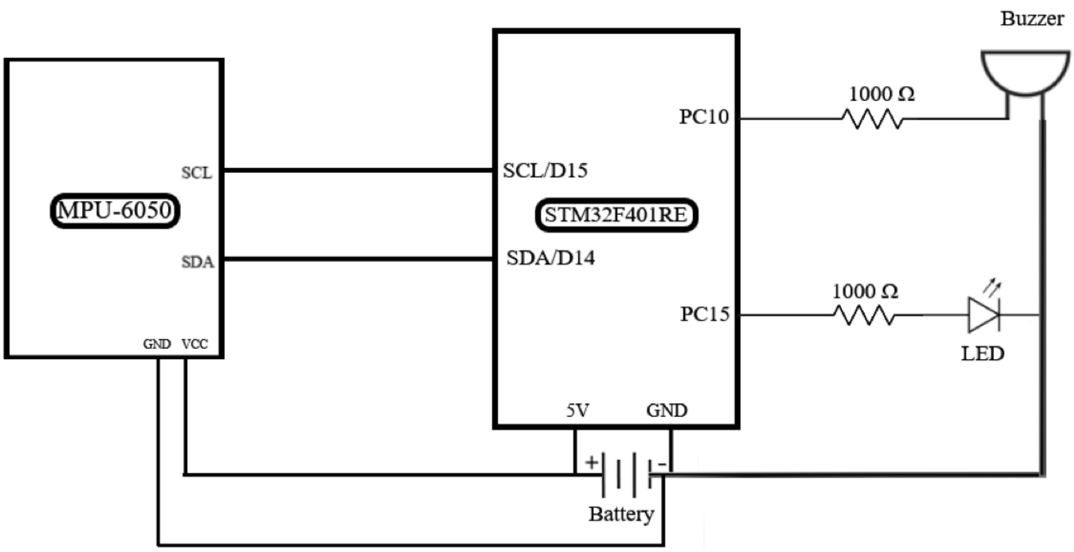
- The HomeSafe Fall Detection device help is worn like a necklace with an adjustable cord.
- Because the device is worn around the neck rather than on the wrist, plane detection is more accurate.
- The device uses a gyroscope and accelerometer similar to our product.
- The device uses a gyroscope and accelerometer to detect the orientation of the user and their velocity.
- Unlike our product, the device also uses a pressure sensor. When the user is falling the pressure inside the device will be lower than the external pressure. Knowing this they are able to detect if the user is rising or falling.

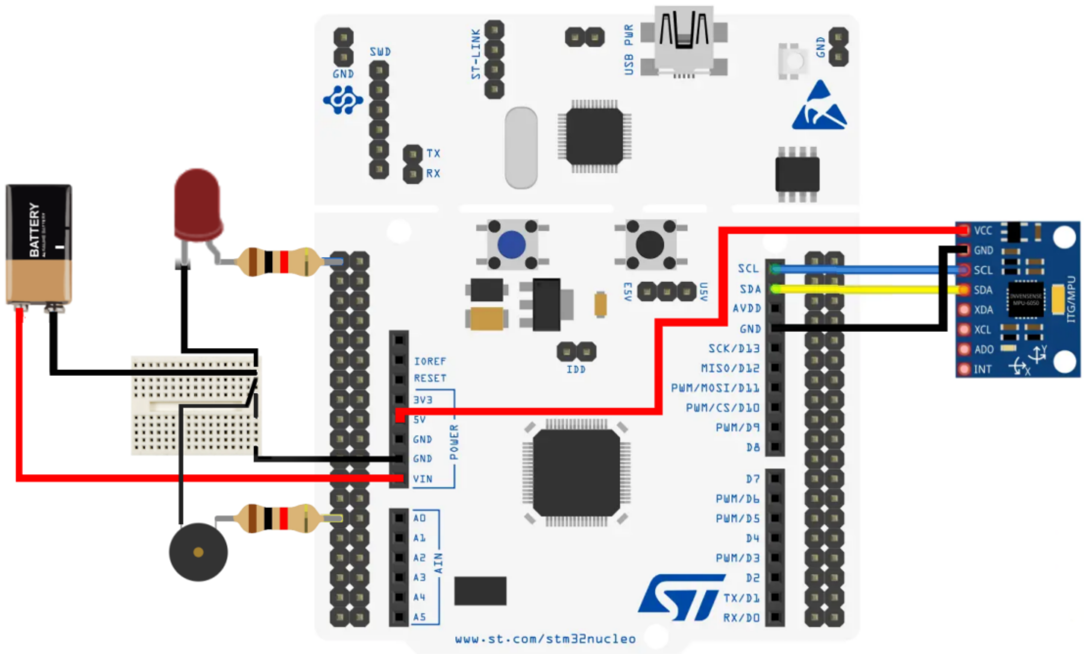
Requirement Specification:

1. **The temperature of wearable device**
   a. Temperatures above **34°C** can significantly impact the thermal comfort of the body segment in contact with the device [11]. The temperature of the device will be measured using a non-contact infrared thermometer.
2. **Real-Time Monitoring Rate**
   a. The system's **STM32F401RE board** must operate with a clock frequency ranging from 50 MHz to 100 MHz so that we have a high fidelity when reading data from the accelerometer/gyroscope. This can be verified with manufacturer datasheets. [20]
3. **Voltage of microcontroller**
   a. An important technical requirement is that the **STM32F401RE board** operates with a **3.3V supply** [3]. According to the IEEE standard for Microcontrollers, the voltage must remain between **+12V to -7V** [4]. This can be easily read using a multimeter.
4. **The accelerometer detection range**
   a. The accelerometer must be able to detect an acceleration of **0 g to 1 g**, to make sure that a fall can be detected in which the acceleration would be near **1 g** [15]. This can be measured by referring to the specifications of the accelerometer.
5. **The gyroscope detection range**
   a. The gyroscope must be able to detect changes at least up to **180°** in any direction and also must detect sudden changes in angle as well [19]. This can be measured by referring to the specifications of the gyroscope.

Design:

Circuit Diagram:





FIRST PRINCIPLE DESIGN/IMPLEMENTATION:

```
# Define constants
average_mass_of_human = 70  # average mass of a human in kilograms
threshold_force = 3 * 9.81  # 3 times the weight of a human in newtons (assuming g ≈ 9.81 m/s^2)
# Define constants
average_mass_of_human = 70  # average mass of a human in kilograms
threshold_force = 3 * 9.81  # 3 times the weight of a human in newtons

# Function to determine if a movement is a fall
def is_fall(average_acceleration_data, time_interval):
    # Calculate net force using Fnet = ma
    net_force = average_mass_of_human * acceleration_data

    # Calculate change in momentum (impulse) using p = F * t
    impulse = net_force * time_interval

    # Compare impulse to a threshold to determine if it's a fall
    if impulse > threshold_force:
        return "Fall"
    else:
        return "Not a fall"

result = is_fall(avg(acceleration_data), .2)
print("Movement is:", result)
```

SAMPLE CALCULATION #1:

$F_{net} = ma$

$p = F_{net}t$

$p = mat$

$p = 70(10.2)(.5)$

$p = 357$

SECOND PRINCIPLE DESIGN/IMPLEMENTATION:

```
def find_peaks(acceleration_data, time_data, peak_threshold, min_peak_distance):
    peaks = []

    # Compute the first derivative of the acceleration data with respect to time
    derivative = compute_derivative(acceleration_data, time_data)

    # Initialize variables to keep track of peak detection
    is_peak = False

    for i in range(1, len(derivative) - 1):
        if derivative[i] > -.5 and derivative[i] < .5:
            peak = find_peak(acceleration_data[peak_start:peak_end])

            # Check if the peak is above the threshold
            if peak > peak_threshold:
                peaks.append(peak)
```

```
        is_peak = False

    return peaks

def compute_derivative(acceleration_data, time_data):
    # Calculate the first derivative of the acceleration data with respect to time
    derivative = []
    for i in range(1, len(acceleration_data)):
        delta_t = time_data[i] - time_data[i - 1]
        delta_a = acceleration_data[i] - acceleration_data[i - 1]
        derivative.append(delta_a / delta_t)
    return derivative

def find_peak(data):
    return max(data)

peaks = find_peaks(acceleration_data, time_data, peak_threshold, min_peak_distance)
print("Detected Peaks:", peaks)
```

SAMPLE CALCULATION #2:

$m = \frac{y_2 - y_1}{x_2 - x_1}$

$m = \frac{9.81 - .62}{1 - .5}$

$m = 18.38$ (approximation of derivative)x

THIRD PRINCIPLE DESIGN/IMPLEMENTATION:

```
def calculate_angle(origNormal, normal):
        dot = dotproduct(origNormal, normal)
        magnitudeA = magnitude(origNormal)
        magnitudeB = magnitude(normal)

        cosOfAngle = dot/(magnitudeA * magnitudeB)
        angle = arccos(cosAngle)

        return angle

origNormal = getGyroscopeReading() //Happens once when calibrated
currNormal = getGyroscopeReading() //Would happen at any given time
angle = calculate_angle(origNormal, currNormal)
print("angle is:", angle)
```

SAMPLE CALCULATION #3:

$let\ a\ = [0, 0, 1],\ and\ b\ = [0, 1, 0]$

$a \bullet b = a_x b_x + a_z b_y + a_z b_z$

$a \bullet b = 0 + 0(1) + 0(1) = 0$

$a \bullet b = ||a||||b||cos\theta$

$cos\theta = \frac{a \bullet b}{||a||||b||}$

$cos\theta = \frac{0}{||a||||b||} = 0$

$\theta = arccos(0) = 90^{\circ}$

Scientific or Mathematical Principles [30 points]:

There are many principles and standards used within the project, however, there are three which are considerably important to the functionality of the device in question.

The first principle is the principle of impulse (change in momentum) within physics. This is equal to $\Delta p = F\Delta t$ where Δp is the change in momentum, F is the applied force on the object and Δt is the change in time. Over very small Δt values (around .2 s), and high values of F (around 3 times the weight of a human in newtons), the force over that time can be dangerous. Thus, using an accelerometer along with the equation $F_{net} = ma$ where we can consider the mass to be the average mass of a human being and the acceleration being returned from the value, and comparing that to the average impulse of a fall, we can determine whether a given movement was a fall or not [7].

Another principle we are using is the principle of peak detection. The idea is to select intervals based on peaks in the acceleration data provided by our accelerometer. If a given interval has a sizable peak over a sufficiently small time interval, there is a much greater chance that a fall has occurred. An easy way to do this is to take the first derivative of the function and look through the x-intercepts of the first derivative [8]. The formula for this is $f'(x) = \lim_{h \to 0} \frac{f(x+h)-f(x)}{h}$.

The last principles is the principals of normals. The normal of a plane is a vector that is perpendicular to that plane. The gyroscope can provide information that helps determine the normal of a plane. Taking the original normal when the user is right side up, you can then read the normal from the gyroscope at any time and compare it to the original. This can be done with the dot product $a \bullet b = ||a||||b||cos\theta$, where a and b are the two vectors, and you can solve for the angle between them [24].

Manufacturing Costs [5 points]

Item	Price (CAD)	Amount	Vendor	Manufacturer	Geographical Location
STM32F401RE [36]	34.99	1	WStore	STMicrocontrollers	Geneva, Switzerland
Electronic Buzzer [29]	8.09	1	Amazon	Gloglow	Shenzhen, China
LED [28]	4.99	100	Amazon	Fan Fei Technology Co., Ltd.	Guangdong, China
Resistors (1000Ω) [30]	9.67	10	Amazon	E-Projects	Tenessee, USA
Wires [34]	12.99	120	Amazon	Elegoo	Shenzhen, Guangdong, China
MPU-6050 [31]	32.50	1	Amazon	Sparkfun	Colorado, USA
Battery Pack	12.99	5	Amazon	LampVPath	Fuzhou,

Holder (9V) [33]					Fujian, China
Battery Pack (9V) [32]	11.47	2	Amazon	Duracell	BETHEL, CT, USA
Breadboard [35]	16.99	3	Amazon	Elegoo	Shenzhen, Guangdong, China

Implementation Costs [5 points]

Installation Manual and User Guide:

Required Components:

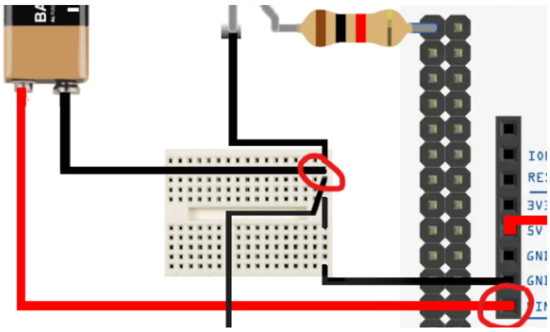
- STM32F401RE - 34.99$
- Electronic Buzzer - 8.09$
- LED- 0.05$
- Resistors (1000Ω) - 1.00$
- Wires - 1.10$
- MPU-6050 - 32.50$

- Battery Pack Holder - 2.60$
- Battery - 5.74$
- Breadboard -5.66$

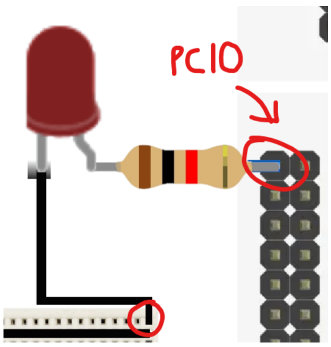
The total cost to build one fall detector would be 91.73 Canadian Dollars.

Building the circuit:

1. Connect the Battery Pack Positive wire to the VIN Port of the STM32F401RE Microcontroller and Connect the Battery Pack Negative Wire to a slot on the furthest row of the breadboard

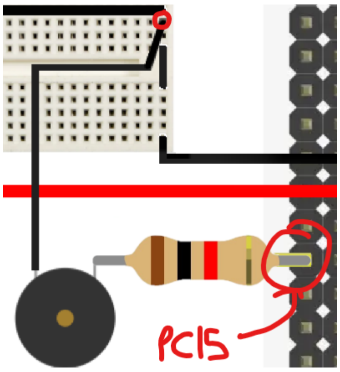


2. Connect one end of a 1000-ohm resistor to pin PC10 and connect the other end to the round side of the LED. Using a loose wire connect the flat side of the LED to the furthest row of the breadboard.

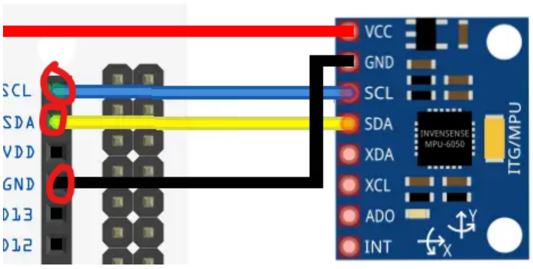


3. Connect one end of a 1000-ohm resistor to pin PC15 and connect the other end to the buzzer. Using a loose wire connect the other end of the buzzer to the furthest row

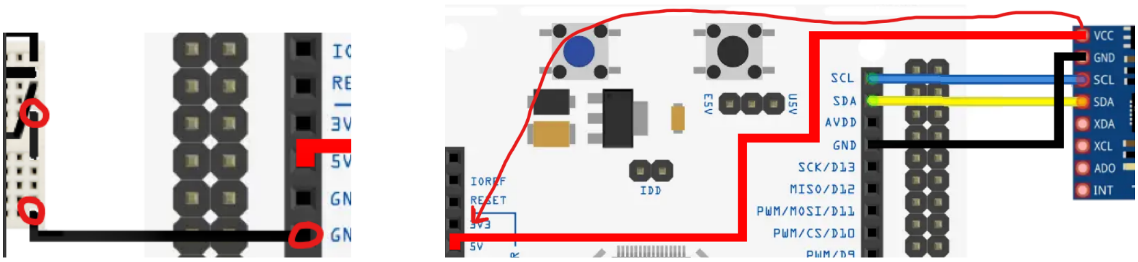
of the breadboard



4. Using loose wires connect the GND SCL and SDA of the MPU-6050 to their respective slots on the STM32401RE



5. Connect one of the ground pins on the STM32F401RE to the furthest row on the breadboard. Finally, connect the VCC of the MPU-6050 to the 5V of the STM32F401RE



Energy Analysis [5 points]

The reference being used is from a National Science Review paper on Wearable energy systems, which gives us a baseline of 300mWh [22]. This is justifiable because the paper specifically mentions this in relation to devices such as smartwatches and so considering the fact that our device has much much fewer components (it is much simpler), our device will also be able to satisfy that baseline. The only place energy could be stored within our device is within the microcontrollers that are used, specifically in any capacitors that are on the boards. Referencing the datasheet for the STM32 board, the capacitors can store 11.4uF [20], and referencing a datasheet for the Leonardo board, they can store 34uF [23]. The Arduino when powered emits 40 mA for each I/O pin, 50 mA for the +3.3V pinout, which is a total of 850mA with all 20 pins [23]. The STM32 uses about 405 mA in total while powered according to the datasheet as well [20].

Risk Analysis [5 points]

If the device is being used as intended, there should be no environmental impact or safety concerns. If the device was used incorrectly (e.g placed in the incorrect position), there may be a minor threat to safety if the user managed to get the device between them and the ground as the fall happens, however the mass of the device is minimal and it would break apart rather than act as a blunt object, thus it would not cause any harm to the user outside of what the user experienced from the fall itself. There may also be a minor risk to the environment since there may be debris from the device. There is not much room for the device to be misused, however, in such a case, the only threat the device itself can pose to a user is if in some way they interact with it as per the situation outlined above, which also includes the same environmental concern within that situation. Some ways the device could malfunction could be a possible false detection of a fall in which case the siren and lights would go off, or if there was some error in the design, the circuit could suffer from some error too, however the device itself does not require much in the way of power which would make this not a major concern for safety.

Test Plan [10 points]

The first test for wearable temperature will be setup by having the device powered on an inert surface for a prolonged period of time. The environment will be free of any heat conductors etc that can affect the temperature of the device. The device will also have a fall simulated with it to activate the siren and LED. The standard that it will be measured against is the temperature that a human finds safe as detailed in the Requirement Specifications (RS). If the temperature found for the device is lower, it will pass.

The second test for clock speed will be set up again by having the device powered on an inert surface for a prolonged period of time. The environment will adhere to proper operating conditions across the components of the device. There are no notable test inputs for this as the test is purely to do with the accelerometer/gyroscope. The standard it’s being tested against is the speed needed for high fidelity readings from the accelerometer/gyroscope again detailed in the RS. If the clock speed found is within 50-100 MHz the test passes.

The third test for voltage limits will be set up again by having the device powered on an inert surface for a prolonged period of time with a multimeter attached to it. The environment will adhere to proper operating conditions across the components of the device. There are no notable test inputs for this as the test is purely to do with the voltage usage of the device. The standard it’s being tested against is the IEEE standard for voltage limits in microcontrollers detailed in the RS. If the voltage is within the range of +12V to -7V, the test passes.

The fourth test for the accelerometer will be set up by having the device powered on. The environment will adhere to proper operating conditions across the components of the device. The device will also have a fall simulated with it so the accelerometer can get it's readings. The standard it's being tested against is the acceleration limits from the accelerometer detailed in the RS. If the acceleration measured is approximately 1g, the test passes.

The fifth test for the gyroscope will be set up again by having the device powered on. The environment will adhere to proper operating conditions across the components of the device. The device will be rotated to provide the input for the gyroscope, both slowly and suddenly. The standard it's being tested against is the angle limits from the gyroscope again detailed in the RS. If the angle measured by the gyroscope from tilting it slowly and suddenly approximately matches the actual angle it was tilted by, the test passes.

Sources:

[1] Government of Canada. “Senior’s Falls in Canada”. canada.ca https://www.canada.ca/en/public-health/services/health-promotion/aging-seniors/publications/publications-general-public/seniors-falls-canada-second-report/seniors-falls-canada-infographic.html (accessed Sept 29, 2023)

[2] The City of Waterloo. “Workforce and demographics” waterloo.ca. https://www.waterloo.ca/en/government/workforce-and-demographics.aspx (accessed Sept. 29, 2023)

[3] STM32 Dynamic Efficiency. MCU https://www.st.com/en/microcontrollers-microprocessors/stm32f401re.htm l (accessed Sept. 20, 2023)

[4] IEEE. ‘IEEE Standard Microcontroller System Serial Control Bus’ https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=159173 (accessed Sept. 20, 2023)

[5] IEEE. ‘IEEE Standard Specification Format Guide and Test Procedure for Linear Single-Axis, Nongyroscopic Accelerometers.’ https://ieeexplore.ieee.org/document/8653544 (accessed Sept. 20, 2023)

[6] IEC. ‘Electroacoustics - Audiometric equipment - Part 1: Equipment for pure-tone and speech audiometry’ https://webstore.iec.ch/publication/32370 (accessed Sept. 20, 2023)

[7] Lawrence Davis. ‘BODY PHYSICS: MOTION TO METABOLISM’ https://openoregon.pressbooks.pub/bodyphysics/chapter/falling-injuries/ (accessed Sept. 20, 2023)

[8] Prof. O'Haver. ‘Peak Finding and Measurement’ https://terpconnect.umd.edu/~toh/spectrum/PeakFindingandMeasurement.htm (accessed Sept. 20, 2023)

[9] IEC. ‘IEC 60601-1:2012 (Ed 3.1) MECA Evaluation Package’

https://60601-1.com/wp-content/uploads/2019/04/meca-60601-1-ed3.1-evaluation-package-beta-2018-11-24.pdf (accessed Sept. 20, 2023)

[10] IES. 'INTRODUCTION TO IES LIGHTING LEVELS & APPLICATIONS' https://www.modern.place/ies-recommended-lighting-levels/ (accessed Sept. 20, 2023)

[11] IEEE. 'Thermal Acceptability Limits for Wearable Electronic Devices' https://ieeexplore.ieee.org/document/9406079 (accessed Sept. 20, 2023)

[12] Werner K. Noell et al. 'Retinal Damage by Light in Rats' https://iovs.arvojournals.org/article.aspx?articleid=2128202 (accessed Sept. 20, 2023)

[13] American Speech-Language-Hearing Association. 'Loud Noise Dangers' https://www.asha.org/public/hearing/loud-noise-dangers/ (accessed September 20th 2023)

[14] Statistics Canada "... number of seniors aged 65 and older grows six times faster than children 0-14" 150.statcan.gc.ca. (accessed September 28th) https://www150.statcan.gc.ca/n1/daily-quotidien/220427/dq220427a-eng.htm

[15] Chris Murphy. 'Choosing the Most Suitable MEMS Accelerometer for Your Application' https://www.analog.com/en/analog-dialogue/articles/choosing-the-most-suitable-mems-accelerometer-for-your-application-part-1.html (accessed September 28th 2023)

[16] Lux Intelligent. 'BS 5266-1 Pocket guide to emergency lighting' https://www.iheem.org.uk/wp-content/uploads/2021/04/Emergency_Lighting_Pocket_Guide_June_2021.pdf (accessed September 28th 2023)

[17] AlarmGrid. 'How Loud Should My Siren Be?' https://www.alarmgrid.com/faq/how-loud-should-my-siren-be (accessed September 28th 2023)

[18] Gryfe CI, Amies A, Ashley MJ. National Library of Medicine. "A longitudinal study of falls in an elderly population" pubmed.ncbi.nlm.nih.gov https://pubmed.ncbi.nlm.nih.gov/596307/ (accessed Sept. 29, 2023)

[19] Maria Seraphina Astriani et al. 'Human Fall Detection using Accelerometer and Gyroscope Sensors in Unconstrained Smartphone Positions' https://www.ijrte.org/wp-content/uploads/papers/v8i3/C3877098319.pdf (accessed September 29th 2023)

[20] STMicroelectronics. 'STM32F401xE Datasheet' https://www.st.com/resource/en/datasheet/stm32f401re.pdf (accessed September 29th 2023)

[21] Digikey, 'NUCLEO-F401RE'

https://www.digikey.ca/en/products/detail/stmicroelectronics/NUCLEO-F401RE/4695525

(accessed October 31st 2023)

[22] Lu Yin (尹鹿), Joseph Wang, 'Wearable energy systems: what are the limits and limitations?' https://academic.oup.com/nsr/article/10/1/nwac060/6561639 (accessed October 31st 2023)

[23] Arduino, 'Arduino Leonardo Schematic'

https://www.arduino.cc/en/uploads/Main/arduino-leonardo-schematic_3b.pdf (accessed October 31th 2023)

[24] Cuemath, 'Angle between Vectors'

https://www.cuemath.com/geometry/angle-between-vectors (accessed October 31st 2023)

[25] Apple, 'Use Fall Detection with Apple Watch'

https://support.apple.com/en-us/HT208944 (accessed October 31st 2023)

[26] Lifeline, 'HomeSafe with Fall Detection'

https://www.lifeline.ca/en/products/homesafe-with-fall-detection/ (accessed October 31st 2023)

[27] Bay Alarm Medical, 'SOS Mobile'

https://www.bayalarmmedical.com/medical-alert-system/sos-mobile/ (accessed October 31st 2023)

[28] Amazon, '(100 Pcs) MCIGICM 5mm LED Light Diodes, LED Circuit Assorted Kit for Science Project Experiment (Multi-Colored - 5 Color)'

https://www.amazon.com/MCIGICM-Circuit-Assorted-Science-Experiment/dp/B07PG84V17/ (accessed October 31st 2023)

[29] Amazon, '12V 85dB Electronic Buzzer, 3-24V Active Piezo Tone Buzzer Alarm Ringer Continuous Sound Cable Length 100mm'

https://www.amazon.ca/Electronic-Buzzer%EF%BC%8C3-24V-Active-Buzzer-Continuous/dp/B07F9Z3CYQ/ (accessed October 31st 2023)

[30] Amazon, 'E-Projects 10EP5121K00 1k Ohm Resistors, 1/2 W, 5% (Pack of 10)'

https://www.amazon.ca/Projects-10EP5121K00-Ohm-Resistors-Pack/dp/B0185FK65K/ (accessed October 31st 2023)

[31] Sparkfun, ‘SparkFun Triple Axis Accelerometer and Gyro Breakout - MPU-6050’ https://www.sparkfun.com/products/11028 (accessed October 31st)

[32] Amazon, ‘LAMPVPATH (Pack of 5) 9v Battery Holder, 9 Volt Battery Holder with Switch, 9v Battery Case with Switch’ https://www.amazon.ca/LAMPVPATH-Pack-Battery-Holder-Switch/dp/B07BXBS93X (accessed October 31st)

[33] Amazon, ‘Duracell - Coppertop 9v Alkaline Batteries - 2 Count - Long Lasting, All-purpose 9 Volt Battery for Household and Business’ https://www.amazon.ca/Duracell-CopperTop-Batteries-all-purpose-household/dp/B0014D0SL8/ (accessed October 31st)

[34] Amazon, ‘Duracell - Coppertop 9v Alkaline Batteries - 2 Count - Long Lasting, All-purpose 9 Volt Battery for Household and Business’ https://www.amazon.ca/Elegoo-120pcs-Multicolored-Breadboard-arduino/dp/B01EV70C78/ (accessed October 31st)

[35] Amazon, ‘ELEGOO 3pcs Breadboard 830 Point Solderless Prototype PCB Board Kit for Arduino Proto Shield Distribution Connecting Blocks’ https://www.amazon.ca/Breadboard-Solderless-Prototype-Distribution-Connecting/dp/B01EV6LJ7G/ (accessed October 31st)

[36] Amazon, ‘ECE 198/MTE 241 Kit’ https://wstore.uwaterloo.ca/ece-198-kit.html (accessed October 31st)