HEART RATE MONITOR

DESIGN DOCUMENT

Version 1.1

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CONTENTS

NEEDS ASSESSMENT

CLIENT:

The client base includes up to 138 members of the Chartwell Clair Hills Retirement Community located in Waterloo Wellington [1]. The average age demographic of the community is 85 years [1]. The starting monthly cost of residence is around $4,575 [1]. This indicates that the client base is in the upper-middle class.

One of the goals of the Chartwell Clair Hills Retirement Community is to support its residents through progressive and chronic illnesses [2]. However, due to the average age of residents being 85, there is a significantly higher risk of heart-related illnesses and conditions. Moreover, due to the large quantity of residents, it is difficult to monitor the cardiovascular health of each and every resident simultaneously. According to Chatwell, residents have access to a call-bell system or personal response pendants to get in touch with staff day or night [3]. However, in the case of a medical emergency (heart attack...), a resident could be unable to use these systems.

COMPETITIVE LANDSCAPE:

- As aforementioned, call-bell systems or personal response pendants are alternatives to our device [4]. These systems address the challenge of being able to monitor and aid seniors 24/7. However, these systems do not work if the resident is unable to press a button to call for help. If a resident has a sudden heart attack, these systems would not help.
- Another competitor is the use of caretakers. This addresses the challenge of monitoring senior citizens [3]. However, for this to be an effective and safe method, a resident must be monitored all the time by a caretaker, which is not feasible for the caretaker.

- Finally, a surveillance system is another competitor [5]. This competitor addresses the challenge of monitoring residents. However, again, since the retirement home is made up of 138 members, it is impossible to monitor everyone at the same time. Moreover, if the person monitoring falls asleep during a shift, they will not realize something is happening.

REQUIREMENT SPECIFICATION:

- Adjustable wrist straps
    - The device must wrap comfortably around the user's arm like a wristband. The average male wrist size from the 1st to the 99th percentile varies between 15.59-19.44cm while the female wrist size varies between 13.61-16.82cm [6]. To ensure almost all people can wear the watch, wrist straps will have adjustability between 15-20cm.

- Display the heart rate of the user with a display panel
    - A heart rate monitor on the top of the device will display an integer value between 0-999 bpm. This range should cover the heart rate of any person as a normal heart rate for an adult ranges between 60-100bpm [7]. Moreover, there is no need to include decimal points as the integer values provide all the information needed for the purpose of the device.

- Light an LED and produce a sound to warn the user when the heartbeat is irregular
    - When the heartbeat is too high/low, the device will warn the user with a blinking LED light and produce a warning sound. This will somewhat ensure deaf and blind users both get warned when their heartbeat is irregular. For the purpose of this product, a 200-500lm LED light will suffice. This amount of light requires around 1-10W of energy which is less than the limit of 30W [8]. Moreover, a typical alarm clock tends to be around 80 dB [8]. The warning sound produced by the

device will be around this amount to ensure the user is alerted.

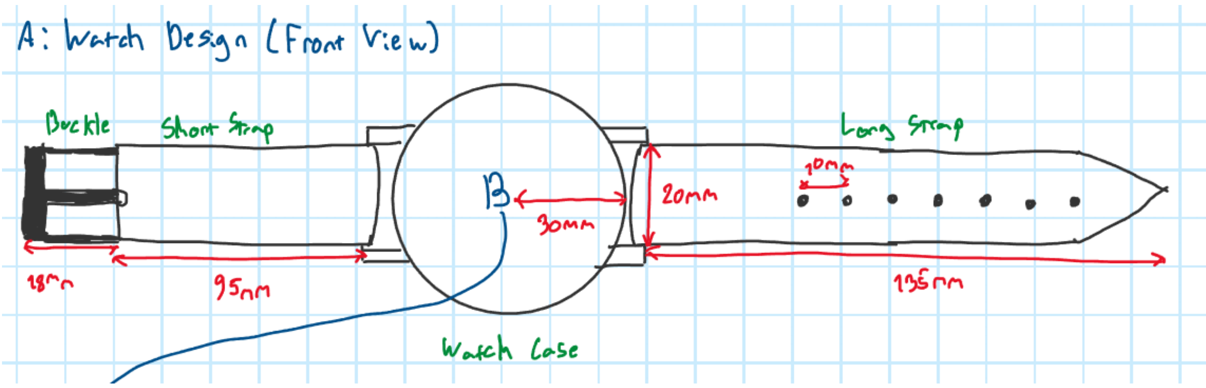
- Displays the type of heart issue
    - Based on the heart rate values recorded by the device over time, the device will have a text-based display to show any irregularities with the user's heartbeat. These will include tachycardia, bradycardia, and a premature heartbeat as a starting point. As eyesight becomes an issue over time for most people, the displayed text will be color-coded to ensure the user is aware of the problem [9].

- 3D printed components
    - 3D printing is a method of creating a three-dimensional object layer-by-layer using a computer-created design [10]. Certain parts will need to be 3D printed to keep the internal hardware of the device intact and to ensure nothing is poking out. The 3D printed components will have to be resistant to around -10-45° Celsius temperature to ensure the device does not break apart due to Canada's harsh weather.

ANALYSIS

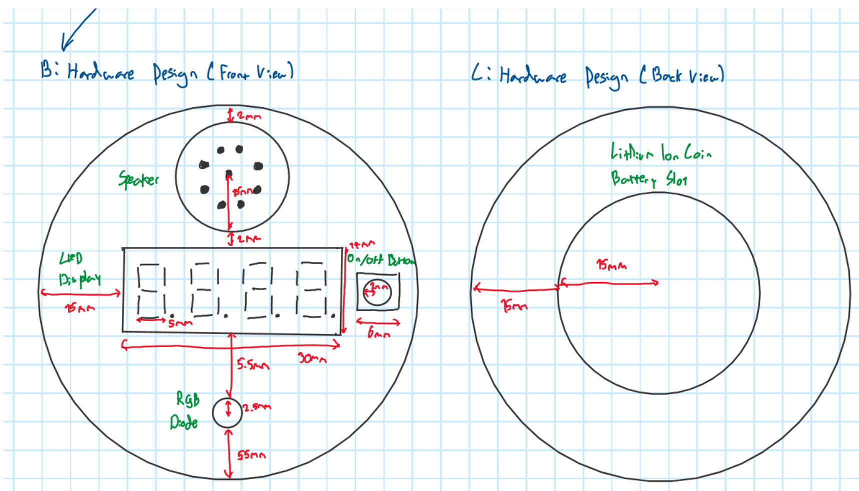
DESIGN:

Below is the general watch design of the device. The two main requirements for this project are a watch case and a strap.



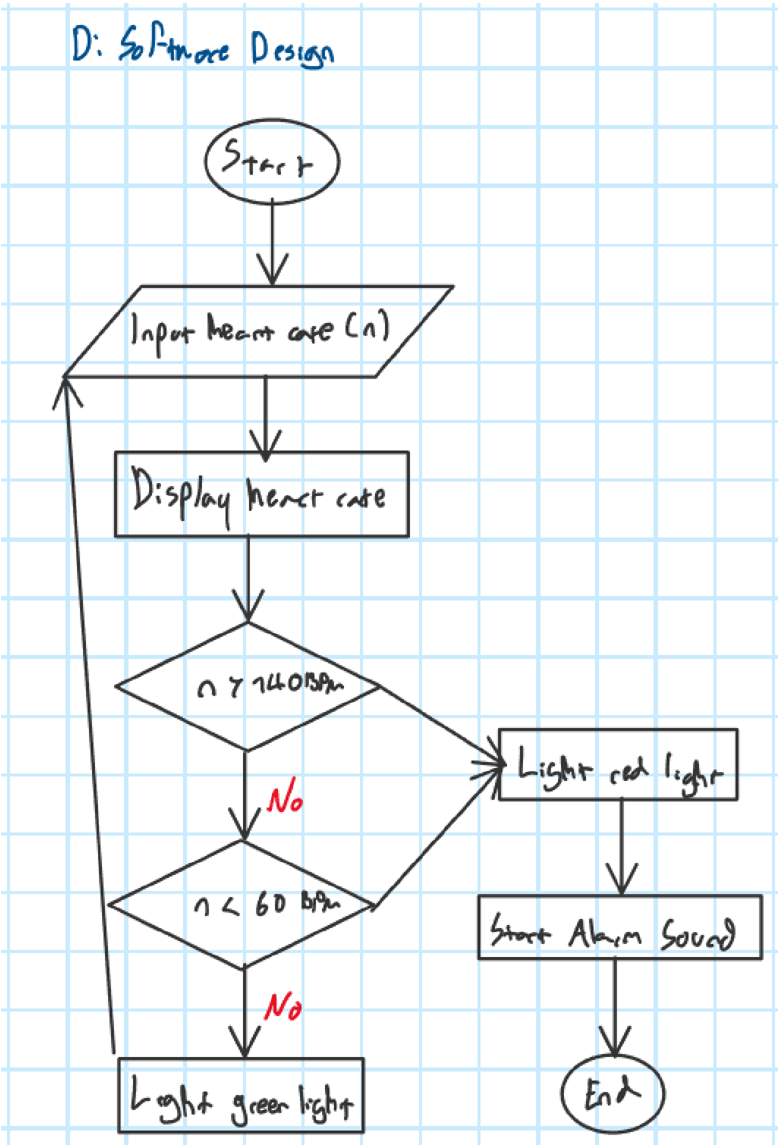
Design of the Hardware Components:

Below are the main visible components of the device covered by the watch case (B). The exact 3D dimensions of these components can be found in their individual datasheets. For example, the speaker: https://cdn.sparkfun.com/__assets/3/8/1/5/4/cvs-1508.pdf. Note that the heart beat sensor and STM32 is not shown in the images below as it is meant to be invisible to the user of the device. The STM32 is connected to each component individually



Software Structure:

Finally, below is a simplified version of the project's main program that is in control of the important hardware components. Note that this design is an oversimplified version of the actual code that will be running in the background.



PRINCIPLES:

Principle 1: Decibel Calculations

To determine how many volts should be supplied to the speakers to produce a specific decibel of sound, the Decibel formula for voltage can be used: [10]

$N_{dB} = 20log_{10}(\frac{V_1}{V_2})$ (where N_{dB} is the decibel, V_1 is the input and V_2 is the output voltage)

To derive this formula, the definition of a decibel, $N_{dB} = 10log_{10}(\frac{P_1}{P_2})$ can be used. To represent N_{dB} as a function of voltage, the voltage must be proportional to the power. According to the power formula, $P = \frac{V^2}{R}$, for the power to be proportional to the voltage,the resistance must stay constant for different power values. [11] Thus, with constant resistance, $P \propto V^2$. Knowing this, $P = V^2R$ can be substituted into the definition of a decibel:

$$N_{dB} = 10log_{10}(\frac{P_1}{P_2})$$

$$N_{dB} = 10log_{10}(\frac{V_1^{\ 2}R}{V_2^{\ 2}R})$$

$$N_{dB} = 10log_{10}(\frac{V_1^{\ 2}}{V_2^{\ 2}})$$

$$N_{dB} = 10log_{10}((\frac{V_1}{V_2})^2)$$

Using log laws, the exponent can be factored out:

$$N_{dB} = 20log_{10}(\frac{V_1}{V_2})$$

With this new equation, the amount of voltage input required can be calculated given the desired output voltage. The desired decibel level of the circuit is$N_{dB} = 80dB$. Meanwhile, the input voltage is $V_1 = 3V$. The formula derived can be used to calculate V_2.

$$N_{dB} = 20log_{10}(\frac{V_1}{V_2})$$
$$\frac{N_{dB}}{20} = log_{10}(\frac{V_1}{V_2})$$
$$\frac{V_1}{V_2} = 10^{\frac{N_{dB}}{20}}$$
$$V_2 = \frac{V_1}{10^{\frac{N_{dB}}{20}}}$$

Values can be plugged in:

$$V_2 = \frac{3V}{10^{\frac{80dB}{20}}}$$
$$V_2 = 3 \cdot 10^{-4}V$$

Thus, 0.0003V will remain after the speaker is used.

Next, the formula for the sound pressure at a defined distance, $P = P_1 - 20log(d)$ can be used. [12] Here, P is the pressure at the distance while P_1 is the pressure at 1 meter, and d is the distance from the speaker in meters. Ideally, the sound should be heard at 80 decibels at a distance of 6m. These variables can be substituted in:

$$P = 80dB + 20log(6m)$$
$$P = 95.56dB$$

Thus, while 80dB of sound pressure is desired, since the distance traveled by the sound is 6m, the actual sound pressure created should be 95.56dB. With this, the actual voltage remaining after the speaker is used is

$$V_2 = \frac{3V}{10^{\frac{95.56dB}{20}}} = 5 \cdot 10^{-5}V$$

Principle 2: Brightness Calculations

To determine how much power is required by the LED lights to produce, the lumens to watts calculation formula, $P = \frac{\Phi}{\eta}$ where P is power in watts, Φ is the luminous flux in lumens, and η is the luminous efficacy in lumens per watt. [13] Using this formula, the power supply to the LED lights can be calculated. The desired brightness of the LED is $\Phi = 500lm$while the luminous efficacy constant of an LED lamp is $\eta = 100 \frac{lm}{W}$. These values can be plugged into the equation:

$$P = \frac{500lm}{100 \frac{lm}{W}}$$

$$P = 5W$$

Thus, 5W of power is required to meet the necessities of the LED light's brightness.

Principle 3: Heart Rate Calculations

Below is a procedure on how the heart rate will be calculated using the device.

- The timestamp of the local maximum of each heartbeat needs to be calculated to <u>measure the heart rate and classify the type of heart issue</u> the user may have. The sensor will provide a voltage value at each timestamp, *V(t)* where the local maxima of *V(t)* represent heartbeats. Since the slope of the function at a maximum will be zero, finding the timestamp of a heartbeat requires setting the derivative of *V(t) = 0* and solving for *V(t)* [14].
    - $\frac{dV}{dT} = 0$

- An alternative method of finding this timestamp would be to find all points of V(t) that are greater than a threshold value that is fine-tuned.
    - $V(t) \geq a$

- In C++, this can be performed with the code below:
    - ```
      vector<int> maxIndices(vector<int> voltages, int threshold) {
              vector<int> results;
              for (int i=0; i<voltages.size(); i++) {
                      if (voltages[i] > threshold) {
                              results.push_back(i);
                      }
              }
              return results;
      }
      ```
      ```

COSTS

MANUFACTURING COSTS:

The project mainly uses the STM32F401RE microcontroller, C++ programming language and some other technical and hardware components. The brief explanation of each of the main components, their approximate costs and the component manufacturers, vendors and geographical locations are as follows:

- STM32F401RE microcontroller
  STM32F401RE is a microcontroller from the STM32F4 series that has an ARM Cortex-M4 core and is suitable for systems that require fast and efficient code execution with low power usage. STMicroelectronics is a major company manufacturing STM32F401RE microcontroller. It is a Switzerland based company which is a massive exporter of STM32F401RE microcontroller to major countries including Canada and the United States. It costs approximately CAD 35 - CAD 40.

  Materials & Technologies for Manufacturing:
    - Silicon wafers
    - Photolithography masks
    - Chemicals and glasses
    - Metal and dielectric materials
    - Packaging materials

- Circuit kit
  To have the ability to connect each component of the circuit, a circuit kit is required. Although designed for Arduino, the ELEGOO UNO will be used. Most importantly, this kit has a breadboard and wires. This will be useful for testing. This product is based in Shenzhen China but has shipping to Canada. The product is around CAD 46.

Materials & Technologies for Manufacturing:

- PCB design and layout software
- Copper
- Silicone
- Plastic and Metal
- Wire and Connectors
- Solder
- Insulating Materials

- 3D printed components

  3D printing is a method of creating a three-dimensional object layer-by-layer using a computer-created design. Certain parts will need to be 3D printed to keep the internal hardware of the device intact and to ensure nothing is poking out. The 3D printed components will have to be resistant to around -10-45° Celsius temperature to ensure the device does not break apart due to Canada's harsh weather. The components can be 3D printed using the Rapid Prototyping Center located in the University of Waterloo at E5-2002 which provides high quality 3D printing and laser cutting. 3D printing costs around $0.10 to $0.50 per gram.

  Materials & Technologies for Manufacturing:

  - Aluminum
  - Steel
  - Bearings
  - Microcontroller board
  - Wiring and connectors
  - Bearings
  - Thermal fuses

- Adjustable wrist straps

  The device must wrap comfortably around the user's arm like a wristband. The average male wrist size from the 1st to the 99th percentile varies between 15.59-19.44cm while the female wrist size varies between 13.61-16.82cm. To ensure almost all people can wear the watch, wrist straps will have adjustability between 15-20 cm. For this, the Balikha wrist strap from Amazon will be used. This product is from China but it ships to Canada. It is around CAD 7.

Materials & Technologies for Manufacturing:
- Plastic
- Metal

- A display panel to display the heart rate of the user
  A heart rate monitor on the top of the device will display an integer value between 0-999 bpm. This range should cover the heart rate of any person as a normal heart rate for an adult ranges between 60-100 bpm. Moreover, there is no need to include decimal points as the integer values provide all the information needed for the purpose of the device. The display panel can be purchased from several hardware stores across Waterloo such as BestBuy or can be purchased online from amazon. The average cost of the display panel varies from CAD 50 to CAD 100.

  Materials & Technologies for Manufacturing:
  - LCD panel
  - Glass
  - Metal
  - Wiring
  - Screws
  - LEDs

- A LED to show light and a speaker to produce a sound to warn the user when the heartbeat is irregular
  When the heartbeat is too high/low, the device will warn the user with a blinking LED light and produce a warning sound. This will somewhat ensure deaf and blind users both get warned when their heartbeat is irregular. For the purpose of this product, a 200-500lm LED light will suffice. This amount of light requires around 1-10W of energy which is less than the limit of 30W. Moreover, a typical

alarm clock tends to be around 80 dB. The warning sound produced by the device will be around this amount to ensure the user is alerted. A variety of LED lights and small speakers are available in the local market. It may cost up to CAD 10 - CAD 15 for both the components.

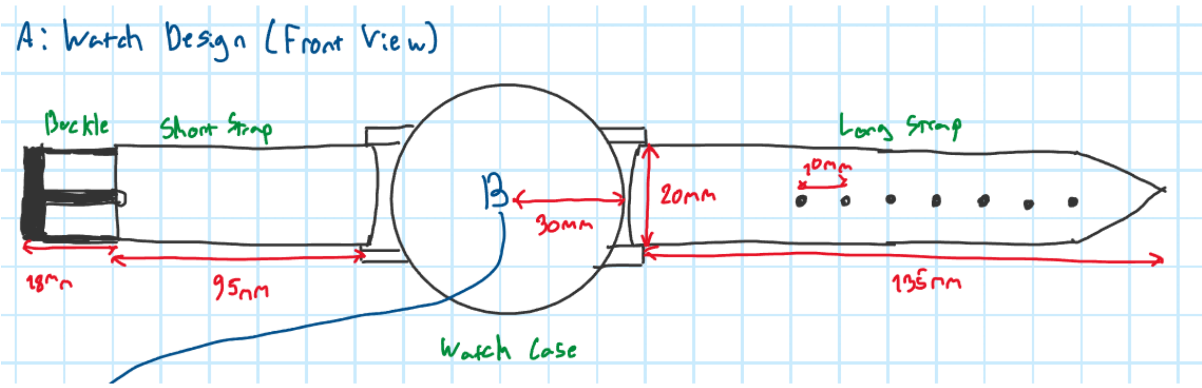
Materials & Technologies for Manufacturing:

- Gallium
- Silicon
- Metal
- Lead

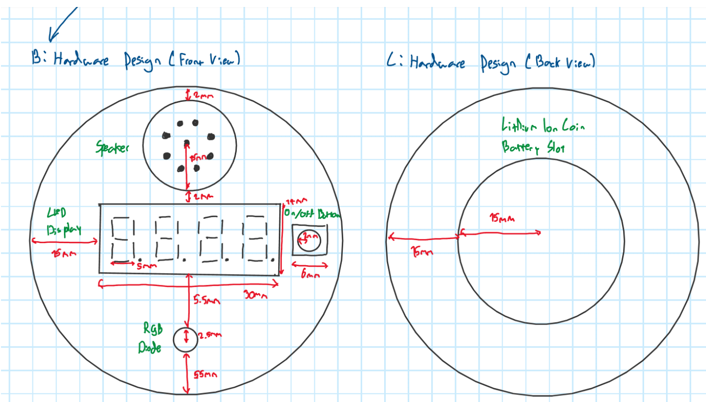
IMPLEMENTATION COSTS:

Installation Manual:

- Connect the wrist strap with the watch case as shown below:



- Within the watch case, connect each component shown below to the STM32 attached to the back of the LED display:



- Attach a coin battery to the back of the watch case.

User Guide:

To effectively utilize this device please adhere to the following instructions:

- Proper Placement
  After installing the device following the provided instructions, ensure that the device is securely placed, in position that the sensor is accurately situated on your wrist. This step is crucial for obtaining readings.

- Power On
  After placing the device on your wrist, locate and press the power button. By doing you will activate the device.

- Instant Readings
  The device will promptly commence its operation. Immediately start measuring your heart rate or pulse rate. The results will be displayed on the screen of the device.

- Understanding the Readings
  The readings are provided in bpm (beats per minute). The usual heart rate for adults lies in the range of 60 to 100 bpm. It is also essential to recognize that factors like stress, medications, and medical conditions can influence the heart rate of the user.

- Warning Alerts
  If your recorded heart rate falls outside of a predefined range rest assured that this device has been designed to alert you. It accomplishes this by activating a blinking LED light and emitting a warning sound. This feature ensures that even individuals with hearing impairments can receive user friendly notifications.

By adhering to these steps users can confidently and conveniently monitor their heart rate or pulse rate especially elderly people in retirement homes using this device while also benefiting from its accessibility and safety features.

RISKS

ENERGY ANALYSIS:

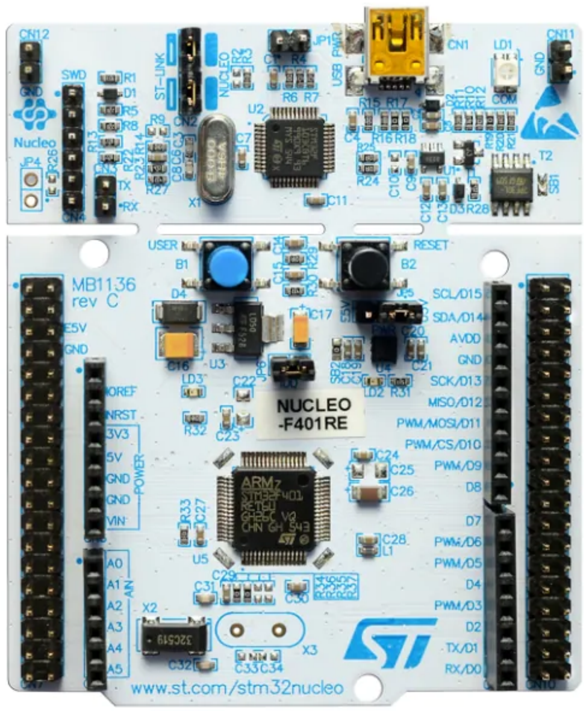
- The device typically requires a very small amount of power, often measured in milliwatts (mW) rather than watts (W). Their power consumption is designed to be extremely low to ensure extended battery life and user comfort.

- The heart rate monitors operate in the range of 10 - 100 milliwatts (0.01 - 0.1 watts) or even less. Since these devices operate at low power, they also consume very little energy. Over the course of a day, a typical wristband heart rate monitor may consume anywhere from a few milliwatt-hours (mWh) to a few watt-hours (Wh) of energy.

- This low power consumption allows users to wear these devices comfortably throughout the day without the need for frequent recharging or battery replacement.

- The research of several giants forums and companies suggested that the heart rate wristbands require very small power and hence consume very small energy for several reasons stated above.

- Since, the core component of the device is STM32F401RE microcontroller with a power consumption of approximately 10 mW to 100 mW, it plays a vital role in the calculation of the entire power of the device. Hence the power of the device, in this case will be close to this range.



STM32F401RE Microcontroller

- Battery capacity used in the device is typically rated in watt-hours (Wh) or milliampere-hours (mAh). Energy stored in the battery can be measured using the following formula:

  Energy (in joules) = Battery Capacity (Wh) x Battery Voltage (V)

  Since the power consumption is very small, the energy stored is also very small, not more than 500mJ of energy.

- The primary source of electrical energy in heart rate monitors is the battery. The energy stored in the battery contains chemical energy, which is converted to electrical energy. It can be calculated as:

  E_electric = Battery Capacity (Wh or J) x Battery Voltage (V)

- The kinetic energy of an object is calculated using the formula:

  KE = $\frac{1}{2}mv^2$

  where "m" is the mass of the object and "v" is its velocity. In the case of a heart rate monitor, the mass of the device is relatively low, and the velocity is also quite low because it's typically stationary on the wrist. Hence, the kinetic energy component is typically negligible or close to zero.

- The potential energy in heart rate monitors is also typically negligible for practical purposes. Potential energy depends on the height of an object above a reference point, and this device is designed to be worn on the wrist, where the height above the ground is minimal. The potential energy of an object is calculated as:

  PE = mgh

- Sum of all the energy components can give the total energy consumed by the device.

  Total Energy = E_electric + E_chemical + E_mechanical + PE + KE + ... (other relevant forms of energy).

- The overall power consumed by the device is approximately in the range 10 - 100 milliwatts (0.01 - 0.1 watts) which is quite less than 30W, the maximum power allowed to be consumed by the device.

- The energy that is consumed and stored including, electrical, chemical , kinetic and potential energies is approximately a bit less than 500mJ which is within the maximum allowed range.

RISK ANALYSIS:

Heart rate monitors, like any technology, can have potential negative consequences on safety or the environment. Here are some possible concerns:

- Even though the device is used as intended, it may cause skin irritation, allergies or discomfort due to prolonged wear of this device. This may lead to extreme skin irritation or allergies, especially if the materials used in the wristband are not hypoallergenic or if the device is worn too tightly.

- If the device is used inaccurately such as wearing the wristband too loosely or not following user instructions, it can lead to inaccurate health data, potentially impacting the user's health management decisions.

- The device is not intended for the user to misuse the device by relying solely on heart rate data without considering other health factors can lead to a false sense of security, causing individuals to overlook important health concerns.

- For instance, Relying solely on heart rate data without considering other factors can result in overexertion during exercise if the user pushes themselves too hard based on heart rate readings. Conversely, it might lead to underexertion if the user avoids necessary physical activity due to misinterpreted data.

- The device is also not intended for sharing sensitive health data via the wristband without proper privacy settings or secure usage which can lead to privacy breaches or data misuse.

- As any other device, the heart rate monitors may also experience certain malfunctions. Sensor malfunction is a common problem. These sensors use light to detect blood flow beneath the skin, and factors like dirt, sweat, or inadequate contact can interfere with accurate readings.

- Battery-related issues, such as a sudden power drain, inability to hold a charge, or battery failure, can disrupt the device's functionality. Wristbands with displays may encounter screen malfunctions, such as dead pixels, flickering, or complete screen failure. Software or firmware issues can result in system crashes, incorrect data processing, or unresponsiveness.

- These malfunctions can cause the following consequences. Sensor issues can lead to inaccurate heart rate readings which can further cause incorrect health assessments and healthcare decisions. Battery problems can lead to the device unexpectedly powering off, potentially causing inconvenience and compromising safety in situations where the device is relied upon.

- Display failures can hinder the user's ability to access critical information or readings, potentially affecting safety if real-time data is essential. Software glitches can cause device malfunctions, leading to incorrect readings or system crashes, potentially impacting safety.

<u>TESTING AND VALIDATION</u>

TEST 1: Adjustable Wrist Straps

<u>Environmental Parameters:</u>

- Temperature must be under 95°C.
- The environment must be dry (no rain or water)
- On a sturdy base (something like a table)

<u>Test Setup:</u>

- 3D print 3 different cylinders of diameter ranging between 15-20 cm (15cm, 17.5cm, 20cm).
- Wrap the wrist strap connected to the watch around each cylinder and place the buckle tongue through the tightest adjustment hole while the cylinder's round end is in contact with the floor/base.
- Turn the cylinder so that its round end is no longer in contact with the floor/base and record whether the wrist strap falls down. Repeat this process for each of the cylinders.

<u>Test Inputs:</u>

- 3 different wrist sizes for 3D printed cylinders (15cm, 17cm, 20cm).

<u>Quantifiable Measurement Standard:</u>

- 3 different Wrist sizes from 15-20 cm.

<u>Pass Criteria:</u>

- The wrist strap does not fall off when turned.

TEST 2: Display the Heart Rate of the User with a Display Panel

Environmental Parameters:

- Temperature must be under 95°C.
- The environment must be dry (no rain or water)
- On a sturdy base (something like a table)

Test Setup:

- Write a simple C++ program to simulate heart beats on the STM32
- Run the program alongside the original program in the STM32 10 times with heart beats from 0 to 200 BPM in increments of 20.
- Record the difference in the heart beat simulated and detected.

Test Inputs:

- Heart beat values from 0 to 200 BPM in increments of 20.

Quantifiable Measurement Standard:

- Difference in heart beat simulated and detected.

Pass Criteria:

- The mean of the absolute difference of heart beats simulated for each test minus the heartbeat detected is 0 ± 1 BPM.

TEST 3: Light an LED and Produce a Sound to Warn the User when the Heartbeat is Irregular

Environmental Parameters:

- Temperature must be under 95°C.
- The environment must be dry (no rain or water)
- On a sturdy base (something like a table)

- Under natural lighting indoors.

Test Setup:

- Use the program created for Test 2 to simulate heart beats ranging from 0 to 200 BPM in increments of 20.
- Record whether the LED is lit up and if a sound is produced for each test.
- To test these values use a light meter and a noise level meter and record down the values.

Test Inputs:

- Heart beat values from 0 to 200 BPM in increments of 20.

Quantifiable Measurement Standard:

- Accuracy of when the LED is lit or when a sound is produced for each test.
- Whether the light is visible and the sound is audible for each test.

Pass Criteria:

- The LED and sound are only activated outside of the 60-100 bpm range.
- The light is visible (200-500lm) and the sound is audible (80-100dB).

TEST 4: Displays the Type of Heart Issue

Environmental Parameters:

- Temperature must be under 95°C.
- The environment must be dry (no rain or water)
- On a sturdy base (something like a table)
- Under natural lighting indoor

Test Setup:

- Use the program created for Test 2 to simulate heart beats ranging from 0 to 200 BPM in increments of 20.
- Record down what is written on the display panel for each test.
- Use a light meter and record down the values.

Test Inputs:

- Heart beat values from 0 to 200 BPM in increments of 20.

Quantifiable Measurement Standard:

- Accuracy of writing on the display for each test.
- The visibility of the display.

Pass Criteria:

- The screen is visible (200-500lm).
- The text written is accurate to the heart condition for each test case. When it is too high, “Low Heart Rate” should be displayed while the heart rate is under 60 BPM and “High Heart Rate” should be displayed when it is over 100 BPM. “Regular Heart Rate” should be displayed when it is between these values.

TEST 5: Internal Circuit

Environmental Parameters:

- Temperature must be under 95°C.
- The environment must be dry (no rain or water)
- On a sturdy base (something like a table)

Test Setup:

- Turn on the watch.

- Use a multimeter to measure the voltage and current across different parts (parts that have resistance) of the watch. Make sure to measure the multimeter around the resistor and current before and after the resistor while measuring.
- Record down these values.

Test Inputs:

- Up to 30W of power is sent through the system.

Quantifiable Measurement Standard:

- The difference between the voltage and current at each part of the circuit with the intended values.

Pass Criteria:

- The mean difference for both the voltage and current is accurate, 0 ± 5%.

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