Home Fitness Aid

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1 Introduction

1.1 Objectives:

Across the world, governments are becoming increasingly concerned with the health of their citizens. According to the World Health Organization, “healthy populations live longer, are more productive, and save more” [1]. Therefore, societies who want citizens who are productive, wealthy, and long-living will encourage a healthier population. One issue affecting the health of a population, obesity, carries an increased risk for diabetes, heart disease, and cancer [2]. Despite this fact, people worldwide and specifically in developed nations are becoming more overweight and more obese. In the United States alone, costs associated with obesity are estimated to be $147 billion [2]. One of the best ways to combat obesity and improve health is to increase physical activity by creating an exercise routine. This idea is backed by the Center for Disease Control, “People who are physically active for about 150 minutes a week have a 33% lower risk of all-cause mortality than those who are physically inactive.” [3]. One of the greatest difficulties in starting an exercise routine is learning how to do exercises properly and counting the numbers of reps accomplished. When one does exercises improperly they risk injury to themselves and possibly others. Furthermore, without a system to keep track of the number and type of exercises performed it is difficult to gauge the success of a workout plan over time. The combination of proper and regimented exercise is essential to succeed in battling conditions like obesity and increasing one’s health.

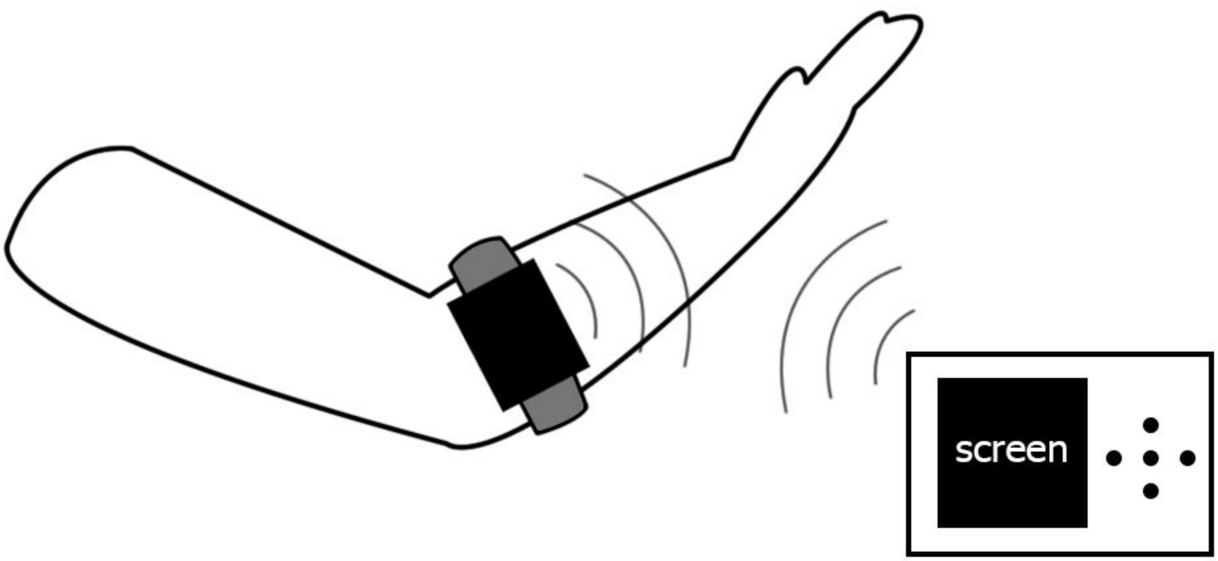
Our goal is to create a wearable that can track the number and quality of exercises done. The device will consist of an accelerometer, a gyroscope, and a microcontroller. The accelerometer will track the speed and time of exercises done and the gyroscope will track the direction and angle of exercises done. The data from the gyroscope and accelerometer will be processed through a microcontroller which will then output its data to a computer. The device will use Bluetooth to communicate with the computer. The computer will be able to process the data from the wearable to inform its user if they are keeping proper form as they go through their repetitions.

1.2 Background:

Other popular fitness wearables, such as Fitbit or Apple Watch, do not have a feature to track an individual's exercise quantity and quality. These devices often feature pedometers, which measure distance ran or walked and total number of steps, but do not measure other information such as the number of push-ups or sit-ups done. Consumers often make purchasing decisions relating to electronics by comparing prices of similar products. Therefore, it is important that our device match or be lower than the cost of these other devices which means the cost of our device must be near or lower than the project budget of $100.

This device must be able to track an individual's quantity and quality of exercise and be a similar price to other fitness wearables whose latest models sell for about $200 and less for older models.

1.3 Physical Design:



1.4 High-level requirements:

The three high-level requirements are:

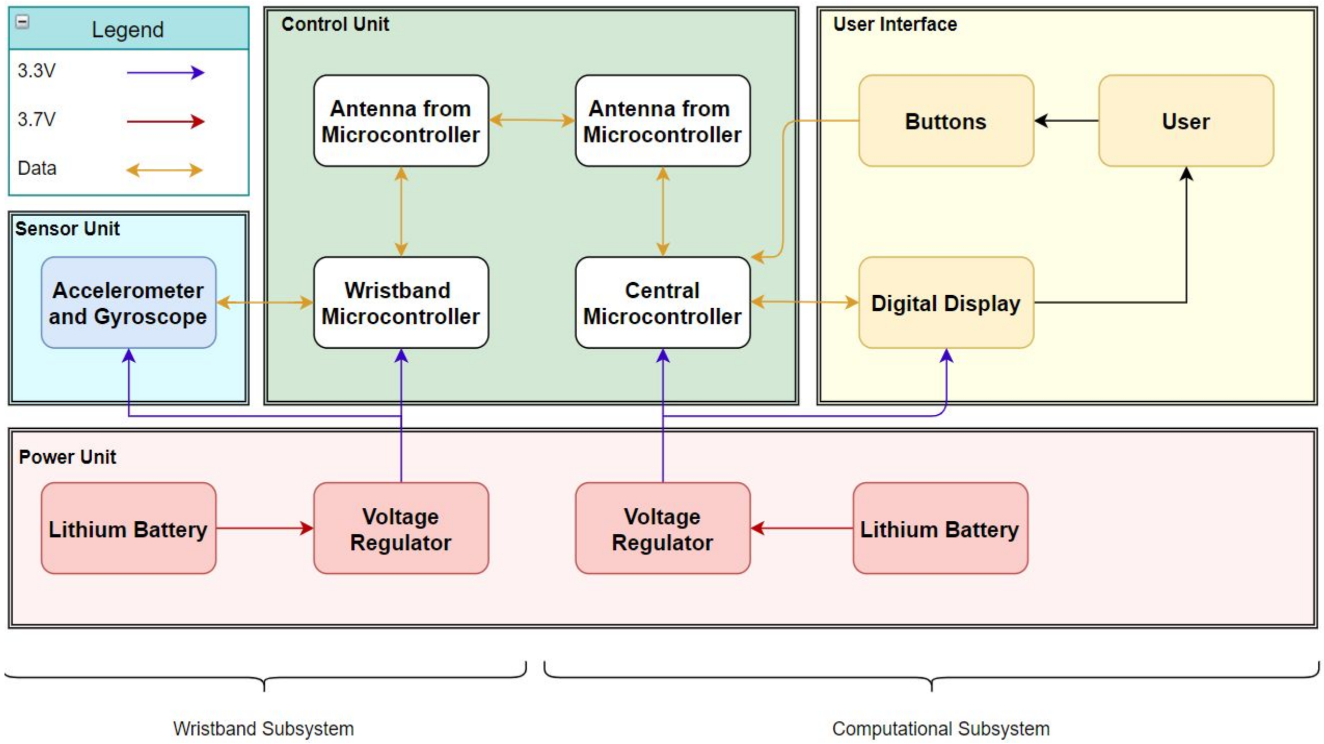
- The number of repetitions of exercises observed in real life must match those observed by the device within a margin of ten percent. Furthermore, data relating to the quality and time length of exercise much match data from the device within a margin of twenty-five percent.

- To consider the data reading a success, data from the wristband microcontroller must be the same as that of the central microcontroller within a margin of error of five percent. This requirement will ensure data processing and bluetooth communication is being done correctly.
- The digital display should update its user-inputted exercises as commanded by the microcontroller within a timeframe of three seconds. The time it takes to communicate between the sensors and digital display should take no longer than five seconds.

2 Design

To meet its operational requirements the device is split into four units: a sensor unit, a power unit, a control unit, and a user interface. The power supply ensures that the device can be powered for the duration of a few exercise sessions estimated to be for an hour every other day with the proper voltage of 3.3 V. The sensor unit contains an accelerometer and gyroscope which measure the direction of and angle of any movement during the exercise relative to the device within an acceptable margin of error. This information is then sent to the control unit which is responsible for processing and outputting the exercise data to the user interface. Furthermore, the control unit can also receive commands from the user interface to start a new exercise, look at data, etc. Both microcontrollers communicate via built-in bluetooth antennas. Data from the control unit will be tested to ensure that the wristband microcontroller and central microcontroller have matching data where applicable to ensure the bluetooth connection is working correctly. The user interface is responsible for displaying data to the user via a digital display and receiving commands from the user to change the operating mode of the device. The digital display should be able to display all relevant information to the user and update based on information from the control unit within a reasonable time frame.

2.1 Block Diagram:



2.2 Functional Overview and Requirements:

2.2.1 Gyroscope and Accelerometer

Overview: We have chosen the LSM6DSL inertial measurement unit as our sensors. It contains both a gyroscope and an accelerometer. The sensors will be incorporated into the wristband subsystem to track the user's positions and to accurately track reps.

Requirements:

- The accelerometer must be able to detect forces of $10 m/s^2$.
- The gyroscope must be able to track the angular velocity of 100 dps (degrees per second)
- Must be able to refresh and obtain new measurements within 1 millisecond

2.2.2 Microcontroller

Overview: The microcontroller, chosen to be a ESP32E, handles Bluetooth Low Energy (BLE) communication between the wristband subsystem and the computing subsystem. The microcontroller will read data from the gyroscope and the accelerometer. The wristband microcontroller then transmits the gathered data to the central microcontroller. The central microcontroller will process retrieved data and read/write to the digital display of the computing unit

Requirements:

- Must be able to transmit/receive BLE signals
- The wristband microcontroller must be able to read and process data retrieved from the sensor unit
- The central microcontroller must be able to read from/write to the digital display
- Must complete the above tasks within 5 milliseconds

2.2.3 Voltage Regulator

Overview: Because the max source voltage of most of our devices is 3.6V and most batteries provide 3.7V, we need a voltage regulator to draw energy from the lithium battery and power the system at a lower voltage (preferably 3.3V)

Requirements: Must be able to take 3.7 V as input and output 3.3 V with a tolerance of ± 0.1V.

2.2.4 Lithium Batteries

Overview: The lithium batteries will power the entire system. The battery in the wristband subsystem should be small enough to fit within the wristband. The battery in the computing subsystem should be no bigger than the screen. Given the constraints in size, the batteries will be limited to powering the entire system for only a few weeks. To overcome this issue, the batteries will be rechargeable.

Requirements:

- Must be able to power all devices within the wearable for at least 14 hours
- Must be rechargeable
- Must meet size requirements described above
- Must be 3.7V

2.2.5 Digital Display

Overview: The digital display will be the means of communication between the product and the user. The LCD display will visualize the current exercise's sets and reps, while allowing for the user to input their routines.

Requirements:

- Resolution/display area must be less than 0.2 $(\text{pixel/mm})^2$
- Display area must be at least 50mm x 50mm to ensure readability

2.2.6 Buttons

Overview: The control input will likely consist of simple push buttons for user input. There would be five buttons. Four buttons will be used for navigation of the menus of the user interface, while the last will be a ‘select’ button.

Requirements:

- Be at least a ¼’’ wide to ensure easy accessibility

2.3 Risk Analysis

A critical function of the “Home Fitness Aid” is the ability to accurately track the amount of reps. Not only is this an important function of the device, it is also the part which poses the largest risk. The first hurdle in tracking the device is establishing a strong connection between the wristband and the computational unit. Both will be equipped with the ESP32E microcontroller which has Bluetooth Low Energy (BLE) capabilities. These devices should only take less than half a second for communication, processing, and displaying the data to the user for meaningful rep tracking. A stable Bluetooth transmitter and receiver will be required to not miscount any reps. A small misconnection would mean the data from the sensor would not register to the computational unit and important data would be lost.

The second problem that attributes to this risk is the considerable amount of various body-weight exercises. There may be exercises that limit the amount of data we can collect from the sensors. For example, if the user decides to attach the wristband to their arm while they are performing push-ups, they would only have very small amount of movements around the wrist. This translates to limited flux in position and angle, and therefore limited data for rep tracking. This will require very precise and fine-grained tracking software. It must be able to tell the difference between small jitters and the actual movement of the exercise. We also can passively minimize this risk by asking the user to attach the band around a part which has a larger range of movement, like their elbow area for push-ups.

We would also like to cover the possible harmful risks associated with the nature of this product. It is very likely that users would like to reach the goals they set for themselves on this device. By doing so, this poses the possible risk of overexerting themselves to dangerous fatigue levels, or pulling a muscle. We will try to incorporate encouraging messages into the product to push them to new heights, but not penalize them if they are unable to reach their goals. This will ensure users will reach their potentials without injuries.

3. Ethics and Safety

There are some common safety hazards in the development and usage of this product. This section will address these safety hazards and what we plan to do to avoid any dangers. We will also address any ethical concerns that could result from the daily use of the product. The IEEE Code of Ethics will be used as a standard to judge any ethical and safety hazards that may emerge.

The first issue we will address is the safe usage of lithium batteries. Lithium batteries present a fire and explosion hazard if they are damaged or not properly managed. We will ensure in our design that the battery will be held in a safe location, and is not susceptible to small falls. Furthermore, we will take precautions to store the device in an environment where the lithium batteries are not subject to temperatures above 45 degrees Celsius or below 0 degrees Celsius where lithium batteries are subject to thermal runaway and possible explosion. Extensive testing of the circuitry will also occur to ensure the battery is not subject to voltages above its tolerances which can lead to cathode breakdown and a release of thermal energy. Lastly, IEEE Code of Ethics #1 states that one must "disclose promptly factors that might endanger the public or the environment" [4]. Since lithium batteries are a known environmental risk we must take care in ensuring that any batteries that are used are disposed of in a proper manner and to inform any users of the device that it contains lithium batteries and is a hazard to the environment if not disposed of correctly.

According to IEEE Code of Ethics #1, one should act in a way to "protect the privacy of others" [4]. Since this device tracks a user's fitness routine it is important to ensure that the user's information is not shared with others without a user's consent. During the development of the project, care will be taken to ensure any information gathered is not shared with third-parties and if this proves to be impossible the user will be informed of what and with whom their data is shared. Furthermore, IEEE Code of Ethics #3 states that one should "avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist" [4]. Therefore, it must be stated to the user that we do not intend to profit off any of the data and that any data generated belongs to them.

This device is also not intended to be used outside or to be exposed to water. We will not test or use this device outside and information will be provided to the user stating that outdoor use or water exposure will damage the device.

Lastly, according to IEEE Code of Ethics #9, one should “avoid injuring others, their property, reputation, or employment by false or malicious actions, rumors or any other verbal or physical abuses” [4]. This device has users exercise to generate information about their fitness routine. As exercise is a known cause of various physical injuries, it is important to inform users about risks related to exercise and advise certain at-risk groups to avoid using this device. Care will be taken according to IEEE Code of Ethics #7, which states to not engage in discrimination, to ensure that all groups told to avoid using this product are groups that are scientifically verified to be at-risk for exercise such as pregnant women or young children [4]. Furthermore, as this device is a wearable, we will choose a material for wearing the device that does not irritate the skin and design the device so the user is not injured if they fall on the device such as choosing an appropriate encasing for the device and avoiding sharp edges in the design.

These mitigation strategies fulfill the standards set by the IEEE Code of Ethics. Ultimately, there are many risks associated in the use of a wearable to facilitate exercise but we believe that the benefits outweigh the risks.

References

[1] World Health Organization, ‘Health and development?’ [Online]. Available: https://www.who.int/hdp/en/. [Accessed 9-Sept-2020].

[2] Center for Disease Control, ‘Adult Obesity Causes and Consequences’, 2020. [Online]. Available: https://www.cdc.gov/obesity/adult/causes.html. [Accessed 9-Sept-2020].

[3] Center for Disease Control, ‘Benefits of Physical Activity’, 2020. [Online]. Available: https://www.cdc.gov/physicalactivity/basics/pa-health/index.htm. [Accessed 9-Sept-2020]

[4] Ieee.org, "IEEE Code of Ethics", 2020. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 10- Sept-2020].