1. **DESIGN REQUIREMENTS/CONSTRAINTS**

Gait Analysis System (GAS) is an inexpensive, easy-to-use system that involves a belt and two ankle bracelets. GAS is designed to record certain aspects of the user’s gait when walking and presents results in a mobile application (app) viewable by physical therapists. Pre-existing methods for gait analysis either are expensive or do not record data; therefore, it is difficult for physical therapists to monitor their patients and determine whether they are improving. To alleviate those difficulties, GAS measures the distance between the user’s feet, the time taken for each step, the time and direction of arm swaying, and the position of the arms relative to the feet. Physical therapists use the measurements within the mobile app for accurate walking examinations.

**1.1. Technical Design Constraints**

GAS integrates various technical design constraints which are noted in Table 1.1.

Table 1.1. Technical Design Constraints

|  |  |
| --- | --- |
| **Name** | **Description** |
| Battery Life | GAS has a battery life that lasts a minimum of one hour. |
| Waist Size/Ankle Size | The belt portion of GAS is adjustable and 91.0 centimeters to 111 centimeters long, while the ankle bracelets are adjustable and 19.7 to 24.0 centimeters long apiece. |
| Measurement Frequency | GAS bases two measurements on the frequency or the rhythm of the users’ walking paces and arm-swinging patterns. |
| Measurement Accuracy | Displayed data values on the app are within ±5 % of the actual values. |
| Memory Storage | The belt’s memory storage holds at least an hour’s worth of data. |

**1.1.1 Battery**

The battery lasts at least an hour since the intended walking sessions completed with the device last thirty minutes to an hour. The walking sessions are assigned by the user’s physical therapist and are to be completed once a week since the physical therapist meets with the user at least once a week [1]. During a walking session, the user will walk for no longer than an hour while wearing GAS; therefore, the battery life lasts a minimum of an hour.

**1.1.2 Waist Size/Ankle Size**

GAS is designed to accommodate various sizes of both American men and women. According to the CDC, the average waistline for American women is 98.3 centimeters, while for American men it is 102 centimeters [2]. According to Military Standard 1472D, the standard deviations for the waistlines of men and women are 8.41 centimeters and 7.34 centimeters, respectively [3]. To accommodate 68.3% of the population, the belt portion of the device is adjustable and is 91.0 centimeters to 111 centimeters long. According to the same source, the average ankle circumference for American women is 21.1 centimeters, while for American men it is 22.2 centimeters. The standard deviations for the ankle circumferences of men and women are 1.78 centimeters and 1.40 centimeters, respectively [3]. To accommodate 68.3% of the population, each ankle bracelet is adjustable and is 19.7 centimeters to 24.0 centimeters long.

**1.1.3 Measurement Frequency**

The width of the space between the users’ legs and the time it takes for each step are measured based on the users’ walking paces. It is necessary that the frequencies at which these measurements are taken adapt to the walking pace of each user since people walk at different paces. If one of the user’s legs is injured while the other leg is healthy, then the user might have an unbalanced walking pace where they step faster with one leg than the other. This also applies to the user’s arm swing, where the taken measurements on the belt adapt to how often the user swings his or her arms back-and-forth. These flexible measurement frequencies allow GAS to accommodate all users.

**1.1.4 Measurement Accuracy**

All displayed values for the physical therapist on the app are within ±5% of the actual value. This accuracy ensures that physical therapists are able to obtain the data necessary for diagnosing a patient and addressing his or her needs in future exercises.

**1.1.5 Memory Storage**

Users wear the device anywhere from thirty minutes to an hour. It is important that at least one-hour worth of data is stored so that the device records the longest possible walking session time provided by the physical therapist.

**1.2 Practical Design Constraints**

Safety, cost, and practicality are some of the considerations for the practical design constraints of GAS. These considerations are noted in Table 1.2.

Table 1.2. Practical Design Constraints

|  |  |  |
| --- | --- | --- |
| **Type** | **Name** | **Description** |
| Manufacturing | Weight | GAS weighs no more than 2.3 kilograms. |
| Economic | Price | The intended manufacturing cost for this device is $150. |
| Cultural | Clothing | GAS can be worn over a variety of clothing. |
| Health & Safety | Safety | Users are unable to trip over the wires that are part of the device. |
| Cultural | Data | GAS records and stores information useful for physical therapists, which includes the average width between the user’s feet, the average time taken for each step, the average time and direction of arm swaying, and the position of the arms relative to the feet. |

**1.21. Manufacturing: Weight**

GAS weighs no more than 2.3 kilograms. In addition to being convenient to manufacture, this device is lightweight and allows users to complete their walking exercises easily at no additional barrier.

**1.2.2 Economic: Price**

The intended manufacturing cost of GAS is $150. This device is unique in that there are no pre-existing gait tools that record data; therefore, $150 is a reasonable price that accounts for the inclusion of high-quality components while still making it accessible to the general population.

**1.2.3 Cultural: Clothing**

GAS can be worn over a variety of clothing, meaning the user does not have to buy new clothes compatible with GAS. This makes GAS easily integrable into the user’s life at no additional fee. Clothing that can be worn with GAS includes jeans, shorts, short-sleeved and long-sleeved shirts, athletic/workout clothing, and light jackets. Clothing incompatible with GAS includes thick, heavy winter coats or pants, contact sports gear, wet suits, dress slacks, suits, skirts, dresses, costumes, or anything else that is not commonly worn during everyday life.

**1.2.4 Health & Safety: Safety**

Two wires connect each ankle bracelet to the belt portion of the device. The wires are arranged in such a way that it is impossible for them to injure the user. The wires each have a knee band that is adjustable in size and position along the wire. This knee band splits the wire into three portions: one connecting the belt to the knee band, one within the knee band, and one connecting the knee brace to the ankle bracelet. The knee brace allows the portions that connect the knee band to the belt and ankle bracelet to be taut, while the knee band holds the wire’s slack. This permits users to bend their knees and walk without tripping over the wires.

**1.2.5 Cultural: Data**

GAS records four different parameters for each step: the average width between the user’s feet, the average time taken for each step, the average time and direction of arm sway, and the position of the arms relative to the feet. These four parameters are displayed on the app for the physical therapists to view. When analyzing a person’s gait, physical therapists look at these specific motions and behaviors of that person in order to determine if the individual is walking correctly. Average width between the user’s feet: If the distance between the user’s feet is too close or too far apart, or if the user crosses their legs when they walk, then the user is either having difficulty keeping balance or moving specific parts of their body. This value is presented in inches and centimeters on the app. Average time taken for each step: The time taken for each step should be the same. If the user is taking longer to step with one foot than with the other, then that foot or leg could be injured and should be looked at by a physical therapist. This value is presented within seconds on the app. The additional values of the average left step time, average right step time, the total number of steps taken, and the total walking time are presented in seconds, seconds, an integer, and in minutes, respectively. Average time and direction of arm swaying: Just like with step time, the time for each arm to sway should be the same. Also, according to physical therapists, the arms of the user should be swaying in opposite directions of each other. The average time of arm swaying is presented in seconds, while a percentage value is used to represent how often the user’s direction of arm swaying was correct. Position of the arms relative to the feet: In order to walk correctly, the user’s leg and arm movement should be opposite of one another. When the left leg is stepping forward, the right arm should be swaying forward at the same time and vice versa. This value is presented as a percentage of how often the user’s arm and foot positions were correct [1].

**1.3 Engineering Standards**

GAS takes various engineering standards into account when it comes to safety and usability. These standards are listed below in Table 1.3.

Table 1.3. Appropriate Engineering Standards

|  |  |  |
| --- | --- | --- |
| **Specific Standard** | **Standard Document** | **Specification / Application** |
| USB 2.0 | Universal Serial Bus Revision 2.0 Specification | USB 2.0 allows connection to the physical therapist’s app. |
| IEEE 82079 Part 1 | IEEE 82079 | An instruction manual is provided so that the product is safely used. |
| IEC 60228 - AWG | IEC 60228 | The wires used in the construction of GAS must be an appropriate size according to AWG. |

**1.3.1 USB 2.0**

GAS communicates with the device via a USB 2.0 connection to sync stored data to an external application used for analyzing results [4].

**1.3.2 IEEE 82079 Part I**

GAS provides users with an instruction manual so that potential misuse does not result in the harm of the user, as per guidelines outlined by IEEE 92079 Part 1 [5].

**1.3.3 IEC 60228-AWG**

GAS uses wires of an appropriate size determined by AWG so that the wires are not a point of fault [6].

**References:**

[1] T. Blackstock, Private Communication, August 2020.

[2] “FastStats - Body Measurements,” *Centers for Disease Control and Prevention,* 2020. [Online]. Available: <https://www.cdc.gov/nchs/fastats/body-measurements.htm> [Accessed 08-Sept-2020].

[3] “MIL-STD-1472D,” *Abbott* *Aerospace Technical Library,* 1989. [Online] https://www.abbottaerospace.com/wpdm-package/mil-std-1472d-human-engineering-design-criteria-for-military-systems-equipment-and-facilities/ [Accessed 07-Sept- 2020].

[4] “Universal Serial Bus Specification”, 2000 [Online]. Available: http://sdpha2.ucsd.edu/Lab\_Equip\_Manuals/usb\_20.pdf [Accessed: 06-Sept-2020].

[5] “82079-1-2019 - IEEE/IEC International Standard for Preparation of information for use (instructions for use) of products - Part 1: Principles and general requirements,” *IEEE 82079 Part 1 – IEEE SA.* [Online]. Available: https://standards.ieee.org/standard/82079-1-2019.html. [Accessed: 07-Sept-2020].

[6] “International Standard IEC 60228,” 2004 [Online]. Available: https://webstore.iec.ch/preview/info\_iec60228%7Bed3.0%7Den\_d.pdf. [Accessed: 07-Sept-2020].