# Design requirements/constraints

Power wheelchair operation, although seemingly innocuous, can be a challenging and dangerous task for individuals who are not accustomed to it. Power wheelchairs can weigh 250 pounds (113.4 kilograms) and can cause harm to both people and property in a collision [1]. Therefore, experts observe people who are learning to use power wheelchairs to ensure they have the dexterity and training necessary to operate their chairs safely. Even during this training, a lack of experience can result in scuffs and scratches on walls and furniture. Train and Go is a system designed to complement virtual reality training environments by providing features to assist wheelchair users in VR.

## Technical Design Constraints

Train and Go meets all technical design constraints outlined in Table 1.1. These constraints ensure a safe and reliable design.

Table 1.1. Technical Design Constraints

|  |  |
| --- | --- |
| **Name** | **Description** |
| Wheelchair Speed | The system is attached to a wheelchair moving no faster than five miles per hour [2]. |
| Detection Distance | The system detects objects within a radius of no more than 2.2 meters. |
| Feedback Latency | This system’s latency for sending feedback to the user in response to an object is no more than 250 milliseconds. |
| Sensor Accuracy | The system’s false detection rate is less than 16 percent. |
| Wireless Range | The system can connect wirelessly to a Quest VR headset within 2.31 meters. |
| Wireless Latency | The wireless latency is less than 250 milliseconds. |

These technical constraints are explained in more detail in the following sections.

### Wheelchair Speed

The average power wheelchair maintains a speed of approximately five miles per hour [2]. Train and Go is designed to affix to a power wheelchair and withstand traveling at those speeds.

### Detection Distance

Train and Go can detect objects within a radius of 2.2 meters so that the user has time to react to Train and Go’s feedback. If an object is detected while the wheelchair is moving at five miles per hour, as in equation (1), then 2.2 meters are traveled in one second. This time is sufficient for a human to react to Train and Go’s feedback before a collision occurs [3].

### Feedback Latency

After detecting an obstacle, Train and Go notifies the user within 250 milliseconds. This latency limit is to give the chair operator a reasonable amount of time to react at varying speeds. The average human reaction time is 250 milliseconds [3]. The average human reaction time combined with the system reaction time of 250 milliseconds allows the user to respond to an obstacle in 500 milliseconds, well before they are likely to collide with the obstacle as established in equation (1) as one second.

### Sensor Accuracy

Train and Go’s false detection rate is less than 16 percent. This rate is the same as other obstacle detection systems that analyze video data to determine whether an obstacle exists [4]. These sensors serve a purpose similar to vehicular systems that minimize collisions and thus react as reliably as those systems.

### Wireless Range

The connection distance between Train and Go and a Quest VR headset is large enough that a person of any height has a wireless connection to Train and Go. Assuming the maximum distance case, Train and Go may be affixed below the wheelchair, and the Quest VR headset may be on the head of an individual in the wheelchair. The average human is less than 180 centimeters tall, and the average wheelchair is 51 centimeters tall [5]-[6]. These heights combine to give 2.31 meters that Train and Go’s wireless signal can span.

### Wireless Latency

Train and Go’s communication with a Quest VR headset occurs quickly so that the user does not notice a delay. The VR headset receives an update within the 250 milliseconds it takes a human to react [3].

## Practical Design Constraints

The practical design constraints listed in Table 1.2 determine, to a large extent, the design and marketing of Train and Go. These constraints include sustainability, accessibility, and economic concerns. These areas of concern are addressed in the design of Train and Go.

Table 1.2. Practical Design Constraints

|  |  |  |
| --- | --- | --- |
| **Type** | **Name** | **Description** |
| Sustainability | Reliability | Train and Go is designed to operate for at least five years without component failure. |
| Sustainability | Sensor Maintenance | Sensor connections are placed strategically to allow simple maintenance or replacement. |
| Usability | Product Versatility | Train and Go offers a flexible packaging system to attach to a variety of wheelchair designs and does not inhibit existing chair functionality. |
| Safety | Collision Detection | Train and Go provides the user with feedback to minimize the risk of collisions with obstacles. |
| Functionality | VR Communication | Train and Go communicates with a Quest VR headset. |

These practical design constraints are explained in more detail in the following sections.

### Reliability

Train and Go is designed to last the lifespan of an individual’s wheelchair. Funding is typically available for a new wheelchair from insurance companies every five years, so Train and Go is able to last until the user needs a new wheelchair, after which time a new Train and Go can be installed [7].

### Sensor Maintenance

All sensors are installed in areas that are easy to reach in case they need to be replaced. The sensors are connected in such a way that they can each be replaced in the case of component failure.

### Product Versatility

Train and Go’s design allows it to be attached to a variety of different wheelchairs without inhibiting their functionality. As a wheelchair training device, Train and Go does not change the handling of the wheelchair during operation.

### Collision Detection

Train and Go provides feedback to the user indicating the possibility of a collision when the user comes too close to an obstacle. This feedback ensures safety while the user is operating the Quest VR headset.

### VR Communication

Train and Go connects wirelessly to a Quest VR headset. This brand of VR headset has been selected by the external source in charge of the National Science Foundation (NSF) project Train and Go is supporting.

## Engineering Standards

Table 1.3 outlines the engineering standards that Train and Go satisfies. These standards from organizations like the International Electrotechnical Commission (IEC), the Institution of Electrical and Electronics Engineers (IEEE), and the Food and Drug Administration (FDA) guarantee industrially acceptable aspects of the design.

Table 1.3. Appropriate Engineering Standards

|  |  |  |
| --- | --- | --- |
| **Specific Standard** | **Standard Document** | **Specification / Application** |
| IP-44 | IEC Standard 60529 | The system is protected from solid particles that are over 1 millimeter in size and from splashes of water [8]. |
| Bluetooth | IEEE 802-15.1 | The system adheres to IEEE Bluetooth standards [9]. |
| Protection Against Electric Shock | IEC 62368 | The electrical components of the system are isolated from the user to prevent electric shock [10]. |
| Wheelchair Accessory | FDA 21 Code of Federal Regulations § 890.3910 | Train and Go satisfies the FDA standards for a wheelchair accessory [11]. |

These engineering standards are explained in more detail in the following sections.

### IP-44

Train and Go complies with Ingress Protection Rating IP44. It states that components should be protected against solid objects greater than one millimeter and should not be harmed by the splashing of water from any direction.

### Bluetooth

Train and Go conforms to the statutes outlined in IEEE 802-15.1, which describes how Bluetooth modules are required to operate. Following this standard ensures wireless compatibility across platforms and consistent operation.

### Protection Against Electric Shock

IEC Standard 62368 gives guidance on protection from electrical shock. The standard classifies direct current and alternating current sources according to their maximum voltage and current magnitudes.

### FDA 21 Code of Federal Regulations § 890.3910

The FDA’s Code of Federal Regulations Section 890.3910 defines what qualifies as a wheelchair accessory. Train and Go meets this definition and can be communicated as such to an insurance agency.

# References

[1] “How much does a wheelchair weigh?” 1800 Wheelchair. <https://www.1800wheelchair.com/faq/how-much-does-a-wheelchair-weigh/>. (Accessed Feb. 16, 2023).

[2] A. Smith. “How fast do electric wheelchairs go?” Mobility Medical Supply. <https://mobilitymedicalsupply.com/how-fast-do-electric-wheelchairs-go/>. (Accessed Feb. 16, 2023).

[3] E. Ackerman. “Enabling superhuman reflexes without feeling like a robot.” IEEE Spectrum. <https://spectrum.ieee.org/enabling-superhuman-reflexes-without-feeling-like-a-robot>. (Accessed Feb. 16, 2023).

[4] Z. Yankun, C. Hong and N. Weyrich. "A single camera based rear obstacle detection system." *2011 IEEE Intelligent Vehicles Symposium (IV)*, Baden-Baden, Germany, 2011, pp. 485-490, doi: 10.1109/IVS.2011.5940499.

[5] M. Roser. “Human height.” Our World in Data. <https://ourworldindata.org/human-height>. (Accessed Feb. 16, 2023).

[6] "Are there standard wheelchair dimensions?” Orange Badge. <https://orangebadge.co.uk/are-there-standard-wheelchair-dimensions/>. (Accessed Feb. 16, 2023).

[7] “Replacing DME.” Medicare Interactive. <https://www.medicareinteractive.org/get-answers/medicare-covered-services/durable-medical-equipment-dme/replacing-dme>. (Accessed Feb. 16, 2023).

[8] *Degrees of protection provided by enclosures (IP Code),* International Electrotechnical Commission 60529, International Electrotechnical Commission, 2019. <https://www.iec.ch/ip-ratings>. (Accessed Feb. 22, 2023).

[9] *Medium access control and physical layers,* Institute of Electrical and Electronics Engineers802.15.1, Institute of Electrical and Electronics Engineers, 2005. <https://standards.ieee.org/ieee/802.15.1/3513/>. (Accessed Feb. 22, 2023).

[10] *Audio/video, information, and communication technology equipment - Part 1: Safety requirements,* International Electrotechnical Commission 62368, International Electrotechnical Commission, 2018. <https://webstore.iec.ch/publication/63964>. (Accessed Feb. 22, 2023).

[11] *Wheelchair accessory,* Code of Federal Regulations Title 21 Section 890.3910, FDA, 2001. <https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.cfm?fr=890.3910>. (Accessed Feb. 22, 2023).