

2. DESIGN REQUIREMENTS/CONSTRAINTS

The Golf Glove must have an unobtrusive design that incorporates stretch and orientation sensors. These sensors are crucial to the product's goal of accurately measuring hand movement that will be displayed to the user. The design must consist of three systems: the garment with integrated peripherals, the wrist-mounted controller, and the coaching software. The garment must measure the user's hand orientation, hand velocity, and wrist motion via its integrated sensors and pass these metrics to the controller. The controller must then broadcast the swing data to a desktop coaching application. This application must display the data giving the user valuable insight into their swing. To achieve the expected functionality and appeal to the user, the design must conform to the following technical and practical design constraints.

2.1. Technical Design Constraints

The Golf Glove must collect data, incorporate a real-time display, and be convenient to the user. Table 2.1 identifies five constraints to the technical performance of the system that will be further detailed in their respective subsections. The device must meet these constraints to ensure accurate and reliable function.

Table 2.1. Technical Design Constraints

Name	Description
Hand Orientation	The glove must determine the angles of wrist flexion, extension, and deviation within a 3° margin of error. Also, the glove must measure wrist acceleration, hand orientation, and hand acceleration within a 5% margin of error.
Wireless Communication	The wrist-mounted controller must communicate wirelessly with a range that will span the average width of a tee box: 30 feet.
Data Display	The system must communicate its measurements to a visual application that will display these metrics through a simple interface. The data can be analyzed after recording a swing, or real-time with both modes supporting a data rate of 100 hertz.
Unobtrusive	The user must not be obstructed while gripping the club with the glove on. The wrist-mounted computer must have a footprint smaller than the average sweat-band size of 3 inches. The sensor wires in the glove must not interfere with swing motion.
Portability	The wrist-mounted controller must be battery powered and not require manual calibration on start-up. The minimum battery life of the system must exceed 5 hours of use.

2.1.1. Hand Orientation

The Golf Glove must measure forearm, wrist, and hand orientation to within a 3° margin of error and the hand velocity within a 5% margin of error. The standard shaft length for a driver golf club is 1.1 m [1]. Using this measurement, a 3° rotation of the wrist amounts to a 5.8 cm movement of the club head, which allows the club head location to be estimated to within one-half of its length [2]. The average golfer's swing speed is about 32 m/s, meaning a 5% margin of error in hand velocity will measure the swing speed to within 1.2 m/s [3].

2.1.2. Wireless Communication

The Golf Glove must maintain a connection with the data display up to a maximum distance of 30 feet. According to Jeff Brauer, a columnist for Golf Course Industry, tee box dimensions vary due to number of expected players. He states that the white tee box, the most common tee box to start from, is normally the only one that may exceed 30 feet in width [4]. Conforming to this constraint enables the product to be fully operational without making the user keep a computer device on their person. Users can store mobile devices nearby, as in the user's pocket or in a golf cart, while still connected. In the event of a dropped wireless connection, the Golf Glove must be able to store several golf swings in memory until the connection is reestablished.

2.1.3. Data Display

The Golf Glove must transmit data to a computer application that will display the measured data. A display application is necessary to show the gathered data to the user in addition to providing feedback, an essential component of the system. The display must incorporate graphs to show hand pressure, hand acceleration, hand rotation, wrist flexion, and wrist extension over time. The device must be capable of collecting data in two modes. In Swing Detection Mode, data must be recorded upon swing detection and sent to the display application upon swing conclusion. The application can then analyze the swing data as one complete motion. A second mode, Real-Time Mode, must collect the sensor data and transmit it to the display application as it is collected. Real-time data display allows the user to practice certain key postures during the swing and ensure that their wrist angles and positions are correct.

2.1.4. Unobtrusive

Since the target audience for this product is a golfer who is trying to improve, the Golf Glove must be as unobtrusive to the golfer's swing performance as possible. On average, male's hands are larger than female hands. In order to fit most of our users, we need a circuit board footprint that can be small enough to fit on both genders. The average width of a female's hand is 7.52 cm [5]. Therefore, the device's footprint must be less than 4 cm in length and width to fit comfortably on the back of the hand.

Also, the wrist housing must not impede proper flexion and extension so the user can maintain a full range of motion. The two main factors for the size of the wrist controller are band width and circumference. The band's width must be larger than 3 in, the width of a common sweat band. The circumference must be adjustable from 5.5 in to 9 in to accommodate a normal range of wrist sizes [6].

2.1.5. Portability

To avoid lengthy wires that may hinder user performance, the device must incorporate a battery system. Additionally, the Golf Glove must not require any additional calibration steps from the user. By removing the need to calibrate, the user avoids an unnecessarily delay in their swing preparation. The garment and controller system must fit in a user's golf bag pocket, allowing the user to easily bring the device onto the golf course without a separate carrying case or bag.

2.2. Practical Design Constraints

Table 2.2 details the practical design constraints for the glove design. Five practical design constraints were selected: economic, environmental, health and safety, manufacturability, and sustainability. Adhering to these constraints will create a low-cost solution that is suited to a golf environment and ultimately values user ease-of-use.

Table 2.2. Practical Design Constraints

Type	Name	Description
Economic	Cost	The Golf Glove must cost less than \$200.
Environmental	Weather-Resistant	The glove must be IP54 water and dust resistant.
Health and Safety	Swing Form	The glove must encourage proper swing form which helps prevent unnecessary stress and injury.
Manufacturability	Modular/Replaceable Parts	The garment and controller must be modular and allow swapping if a subsystem fails.
Sustainability	Battery Life, Safety, and Rechargeability	The glove must have adequate battery life of at least 5 hours.

2.2.1. Economic

The total cost of the sensor glove and controller must be under \$200 to make the Golf Glove competitive to other products on the market. Although other golf tracking products are around this price, the Golf Glove's additional functionality that specifically tracks and analyzes wrist movement through flexion and extension sensors justifies the price. Additionally, the glove component must be separate from the controller to make either part replaceable for a lower cost than replacing the entire device.

2.2.2. Environmental

Due to the need for sustained use in potentially wet or dusty environments, the Golf Glove's design must conform to the Ingress Protection (IP) standard. The product's main enclosure and sensors must be unaffected by dust accumulation and water sprays.

2.2.3. Health and Safety

Since the Golf Glove is designed to be a consumer training aid, it must not harm the user during normal operation. The main objective for the device is to promote proper swing technique; this includes indicating and correcting improper and harmful form. For example, gripping the golf club too hard in the top half of the hand during a swing can result in elbow injuries [7]. The glove will measure pressure on the top and bottom halves of the palm so that the user can be notified when they are putting too much pressure on the club with the wrong fingers. The coaching application must compare the users swing to one with proper form to identify deviations from proper technique. Promoting proper technique will result in fewer unnecessary injuries. Following, the device must inherently promote the user's health.

2.2.4. Manufacturability

The design must efficiently use of modern, easily-sourced components wherever possible. Therefore, Golf Glove must use components that have large amounts of community and manufacturer support. The garment and wrist controller must be modular to allow the user to replace either piece without having to replace the other. In the event of a depleted battery, the system must account for replacement to reduce waste and allow for prolonged system use. The components and housing must allow for efficient creation on a production line.

2.2.5. Sustainability

The design must contain a battery system of sufficient capacity to power the device for a minimum of 5 hours. This time constraint will ensure the device is operation throughout an average 18-hole round of golf [8]. The power system must contain a protection circuit to prevent overcharge, overdischarge, and short circuit situations. Overdischarge occurs when the user forgets to turn the device off and results in a permanently damaged battery. Overcharge occurs in the event of a charger malfunction and can cause rapid discharge of the battery into unwanted places. Overcharge and overdischarge are characterized by the battery reaching a voltage over 4.2 V or under 3.0 V respectively [9]. Lastly, short circuits occur in events of corrosion and cause may damage to the circuit itself. The battery must charge in under 2.5 hours so that the user could theoretically charge it between their free time between golf holes.

2.3. Appropriate Engineering Standards

The engineering standards identified in Table 2.3 target the environmental and health and safety constraints for the device.

Table 2.3. Appropriate Engineering Standards

Specific Standard	Standard Document	Specification/Application
IP54	EN 60529	Rule 5 for dust protection states that the dust quantity allowed to enter or deposit on the system does not impact the system's functionality. Rule 4 for water protection states that water sprayed from any direction against the machine must not cause damage [10].
Restriction of Hazardous Substances Compliance	RoHS-1	The device must not contain substances banned under RoHS [11].
ICNIRP High Frequency EMR Guidelines	ICNIRP	Whole body and local body Specific Absorption Rate due to human exposure to RF fields from wireless devices must not exceed certain levels [12].

2.3.1. Environmental

The device must adhere to the IP54 standard. Defined in Table 2.3, the IP54 standard qualifies the dust and water ingress to the device. IP54 provides a sufficient level of protection from both dust and water, which are two environmental factors that golfers often face. The standard states that while water and dust may interact with the device, the device operation must not be harmed [10].

2.3.2. Environmental Materials

The device must be RoHS compliant. RoHS details several hazardous materials that should not be used in consumer products. To achieve compliance, the design must not contain any of the materials listed so that the device will not result in excess pollution when discarded or cause harm to the user. RoHS is defined in depth throughout Directive 2002/95/EC of The European Parliament [13].

2.3.3. Health and Safety

The device must conform to the International Commission on Non-Ionizing Radiation Protection (ICNIRP) standards for limiting exposure to electromagnetic radiation (EMR) fields. To achieve this, the device radiation will be measured with International Electrotechnical Commission (IEC) 62209 which defines standards surrounding the Specific Absorption Rate (SAR) due to human interaction with Radiofrequency (RF) EMR [14]. Following the ICNIRP threshold of General Public Exposure for mobile devices, the device's whole-body SAR rating must not exceed 0.8 Watts per Kilogram (W/kg) and local-body SAR rating must not be above 4 W/kg [14].

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