

List of Abbreviations

BPM – Beats per Minute

EMI – Electromagnetic Interference

GPS – Global Positioning Satellite

NCAA – National Collegiate Athletic Association

2. Design Constraints

The Zotikon system assists athletes and trainers by providing real-time data monitoring on athletes while they perform. The system is composed of two subsystems: the athlete-worn device and the trainer station. The athlete-worn device collects the essential indicators about the athlete in real time and transmits it to the trainer station for monitoring purposes. This allows for more adaptive workouts and finely-tuned recovery periods. This section details the constraints that will define the Zotikon system. The section is composed of two major subsections. Section 2.1 describes the technical design constraints that serve to constrain the hardware and software performance of the Zotikon system. Section 2.2 describes the practical design constraints that detail realistic engineering standards that must be met to ensure the Zotikon system will perform under real-life conditions.

2.1. Technical Design Constraints

Table 2.1 contains the five technical design constraints for the Zotikon system.

Table 2.1. Technical Design Constraints

Name	Description
Transmission Range	The Zotikon system must be able to reliably transmit data to at least 70 meters in a noisy environment with radio interference with a success rate of at least 90 percent.
Max Beats per Minute (BPM)	The maximum beats per minute the athlete-worn device must be able to measure is 220 BPM.
Simultaneous Users	The monitoring station must be able to receive data from 11 athlete-worn devices simultaneously.
Runtime	The athlete-worn device must be able to operate continuously for no less than 4 hours.
Skin Temperature Measurable Range	The athlete-worn device must be able to measure temperatures in the range of 15°C - 47°C with 0.25°C accuracy.

2.1.1. Transmission Range

The Zotikon system must be able to transmit data reliably at least 70 meters in an environment with heavy electromagnetic interference with a success rate of at least 90 percent. Zotikon must meet range requirements for most common indoor low-contact sports such as volleyball, tennis, basketball or soccer. The largest field among these popular sports is the soccer field. According to the United States Soccer Federation, the recommend size, for a professional court, is 60.1 meters by 26 meters [10]. The diagonal

from this dimension is around 65 meters. This distance determines the minimum transmission range of 70 meters to ensure communication from any location on the playing surface. If a sporting event is crowded, spectators' phones and other electronic devices will emit electromagnetic interference. The Zotikon system must be able to transmit data reliably in a noisy environment, ignoring any radio interference, with a success rate of at least 90 percent.

2.1.2. Max BPM

According to the Centers for Disease Control and Prevention, a person's typical maximum heart rate is defined by subtracting the person's age from 220 [11]. Given that 220 BPM sets the upper limit for the human heart rate, the Zotikon system must be able to accurately read a heart rate up to that limit. The slowest the human heart will beat occurs when the body is at complete rest, also known as the resting heart rate. Athletes, generally, have lower resting heart rates than the average human, so the Zotikon system must be able to measure heart rates down to 20 BPM.

2.1.3. Simultaneous Users

Zotikon must be able to support enough simultaneous users to allow the trainer to track all active athletes at one time. Zotikon will be able to support 11 simultaneous users. There will be at most 11 athletes on the field for a team at one time in the NCAA. This will ensure that all active athletes' vitals are relayed to the trainer's device.

2.1.4. Runtime

A four hour minimum runtime allows for continuous data collection from athletes playing in common American sports. One of the longest college basketball games lasted for three hours and forty-six minutes [6], and the average NCAA football game lasts for approximately three hours and twenty-four minutes [7]. A four hour minimum runtime would accommodate athletes for both of these popular sports by providing continuous data collection for, at least, the average duration of the respective games. Four hours would also provide ample time for collecting training data during exercise or drills.

2.1.5. Skin Temperature Measurable Range

The skin temperature is a measurement intended to help trainers prevent athletes from becoming overheated. According to Robert Freitas, the skin is the largest organ in the body and is crucial for maintaining a healthy core temperature of 37°C [8]. In order to effectively measure skin temperature, the sensor must be able to detect temperatures between 15°C and 47°C with a reasonable accuracy of 0.25°C. Based on medical research from Freitas, the average skin temperature is 32-35°C [8]. Another researcher, Bean, has recorded cases of the lowest skin temperature reaching approximately 25°C on the toes, which are farthest from the heart, the center of core body temperature [9]. Even though this device is not intended to be worn on the toes and the lowest record skin temperature in the chest region is 32°C, the data measurement range is sufficient to capture all possible skin temperatures on any part of the body. The 0.25°C accuracy ensures that small increases in skin temperature are observed and reported, which provides trainers with the best data to make decisions about their athletes.

2.2. Practical Design Constraints

Table 2.2 contains the five practical design constraints for the Zotikon system.

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Type	Name	Description
Economic	Cost	The athlete-worn device will cost less than \$150 per unit. The monitoring station software package, or trainer station, will cost less than \$1,500. The total cost of a system with 10 measurement units and 1 monitoring station will be less than \$3,000.
Manufacturability	Size	The athlete-worn device must have maximum dimensions of 152mm x 152mm x 38mm.
Environmental	Physical	The athlete-worn device will be IP64 compliant and able to operate in temperatures between -40°C and 85°C.
Sustainability	Longevity	The athlete-worn device must be easily rechargeable. The software for the trainer's station must be capable of software updates over time.
Health and Safety	Safety	The athlete-worn device cannot deliver any amount of electrical current or voltage to the athlete that would cause an electrical shock. The device must also be constructed to prevent physical damage to the athlete.

2.2.1. Economic

The Zotikon system is composed of two components: the athlete-worn device and the monitoring station software package. From market research, popular system packages contain 10 athlete-worn devices and 1 monitoring station software package. This common system is how the Zotikon system is compared for competitive analysis in the market. The objective is to ensure the Zotikon system, as a whole, will be price-competitive with other vendors, such as those referenced in Section 1.2. Competitive vendors offer systems that range from \$1,600 to over \$10,000 with most of the widely used products being at the higher end of that range. To make the Zotikon system competitive, the system will cost \$3,000 or less. The athlete-worn devices will cost \$150 per unit, and the monitoring station software package will cost \$1,500. While this goal does not place the Zotikon system as the least expensive option in market, the features that Zotikon provides are only offered by vendors at the high end of the price range. The primary selling point is that the Zotikon system offers the functionality of the high end product at a competitive cost with the low end products.

2.2.2. Manufacturability

The athlete-worn device must be designed so that it can be manufactured in bulk without an excessive amount of labor due to the volume of units that may be required. In order to keep the athlete-worn device usable, it must be manufactured to fit under a jersey or uniform without causing the athlete noticeable discomfort by impeding their normal athletic activity. According to First In Architecture, the average shoulder width for women is around 395 mm [12]. This determines the size constraint of the athlete-worn device. The wearable must be at least half that size in length and width so it will fit comfortably in the area just below the sternum. The device must be less than 38mm thick so it can be concealed under a uniform and still be comfortable.

2.2.3. Environmental

The athlete-worn device is subjected to a variety of environmental conditions where the device must continue to operate properly. Per the Ingress Protection (IP) standards, the athlete-worn device should meet IP64 standards which require the device to be totally protected against dust and protected against splashes of water from all directions. This requirement ensures that the device continues to operate when affixed to a sweating athlete. The device must also be able to operate in the commercial temperature range of -40°C to 85°C. This is based on the Altera standard for commercial and industrial operating temperatures [13]. Commercial standards specify a range of 0-85°C which is insufficient for the athlete-worn device because there may be occasions where athletes train or compete in temperatures below freezing. Due to this, the minimum temperature was expanded to -40°C which is the specified minimum temperature for industrial components. These constraints should adequately constrain the design to ensure the athlete-worn device is functional in all possible training environments.

2.2.4. Sustainability

A rechargeable athlete-worn device frees the user from needing to buy a new set of batteries for the device every four hours. With a rechargeable battery that comes with the device, the design for the device does not need to take into account the availability of consumer batteries. The size, shape, and energy density can be left to the designer of the device. If multiple devices are owned by a user, one device can charge while the other is in operation, giving more freedom to the user.

The software included in the Zotikon system for the monitoring station must be maintainable and able to be updated. As the needs of the user mature, the system must be able to adapt by improving features and eliminating bugs. With the ability to update the software, features provided by new hardware can be incorporated into the Zotikon software. Algorithms for data analysis can be finely tuned and grow in number.

2.2.5. Health and Safety

The Zotikon system must be able to safely measure the heart rate of the athlete. The athlete-worn device has electrical leads that are exposed to the chest of the athlete. The athlete must be safe from electrical shock or burns. The wearable device must be small enough to be worn underneath a jersey. These devices must be worn without posing harm to the athlete wearing it or any other athletes. There can be no sharp edges that could pierce the skin of an athlete.

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