AlertAthlete: A Real-time Alert Tracker for Outdoor Athletes in the Summer

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Abstract

AlertAthlete is a mobile device that tracks environmental threats for outdoor athletes in the summer. It considers the wet-bulb globe temperature (WBGT), ultraviolet index (UVI), and chance of rain and lightning as the threat indicators. These indicators help athletes to be more aware of the risk of heat related illnesses, risk of skin cancer, and the safety of practices/matches. AlertAthlete is implemented with a battery-operated RP2040 microcontroller and a batteryless e-ink display. MicroPython code periodically downloads environmental forecasts from the National Oceanic and Atmospheric Administration and OpenWeatherMap. The forecasts and suggested precautions are then shown on the e-ink display. AlertAthlete aids athletes to take early precautions, such as taking breaks in the shade, extra water, and sunscreen in order to ensure their safety and best performance.

X.1 Introduction

Temperatures have been rising in recent years, and we can feel it. 2023 was the hottest year since 1850, and then 2024 topped that and became the hottest year on record [1, 2]. In the US, at least 2,325 heat-related deaths were reported in 2023 [3]. Though 2025 is thought to be milder thanks to a La Niña, strong trade winds that cause the North to be cooler, it is still very hot [4].

These high temperatures bring health risks to anyone, but especially outdoor athletes. Physical activity in such grueling environments threatens the athletes with sun exposure risks such as heat-related illnesses and sunburn.

This project aims to aid those summer athletes to be more aware of the environmental threats in their activity and take precautions early enough to ensure their safety and performance. To achieve this goal, a portable device called AlertAthelete is created. AlertAthlete tracks the wet-bulb globe temperature (WBGT), ultraviolet index (UVI), and chance of rain and lightning as the threat indicators. WBGT quantifies the heat stress on the body in direct sunlight and indicates the risk of potential heat stroke. UVI quantifies the intensity of UV radiation, which causes sunburn, and indicates the risk of potential skin cancer. Rain and lightning impact the safety of athletic practices/events.

AlertAthlete is implemented with a battery-operated RP2040 microcontroller, a batteryless e-ink display, and a real-time clock (RTC). It runs MicroPython code that operates through deep sleep cycles with the RTC and periodically downloads environmental forecasts (WBGT, UVI, and chance of rain and lighting) from the National Oceanic and Atmospheric Administration (NOAA) and OpenWeatherMap. It also shows the forecasts and suggested precautions on the e-ink display (Figs. 1 to 4). AlertAthlete is a credit card-sized device, and it is as light as 1 oz (30 grams). Athletes can put it on their bag to look at easily. Its battery life is about 22 hours with its default operational settings, which is long enough for an athletic practice/event.

Fig. 1: AlertAthletes on a Tennis Bag

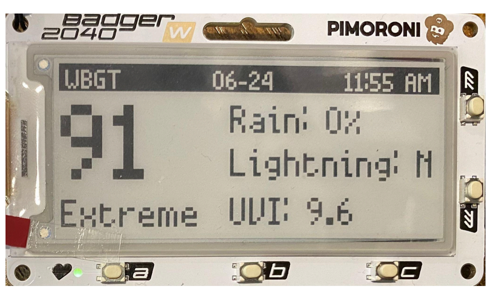

Fig. 2: AlertAthlete’s Main Screen

Fig 3: WBGT-based Suggestion for Activity Adjustment

Fig. 4: UVI-based Suggestion for Sun Protection

X.2 Background

This section describes the environmental threat indicators used in AlertAthletes.

X.2.1 Heat-related Illnesses

Heat-related illnesses such as heat cramps, heat exhaustion, and heat stroke should be taken into concern when doing sports and other outdoor activities in the summer months. Heat stroke is the most serious heat-related illness and a top cause of preventable death for high school athletes [5, 6, 7]. Symptoms of heat stroke include high body temperature, sweating profusely, dizziness, confusion, headache, losing consciousness, and seizures.

Heat stroke occurs when the body is overheating too much to regulate its temperature. High air temperature and direct sunlight exposure increase body temperature. Exercise (muscle contraction) also causes an increase in body temperature. During intense exercise, heat production is 15 to 20 times greater than at rest and can raise the body core temperature 1°C (1.8°F) every 5 minutes unless heat is removed [8].

The body strives to regulate its temperature by releasing heat from the skin via evaporation of sweat. Wind accelerates the loss of heat. However, when dehydrated, the sweating mechanism does not work properly. It is also impaired as humidity increases. No extra heat loss can be expected when there is no wind as well. Due to these factors, the body fails to cool down and causes heat stroke. When heat stroke occurs, the body temperature can rise to 105°F (40.5°C) or higher in 10 to 15 minutes [9].

X.2.2 Wet-Bulb Globe Temperature (WBGT)

Wet-bulb globe temperature (WBGT) is the most effective method to estimate the threat of heat-related illness. It integrates the influences of sun exposure, air temperature, humidity, and wind movement. It is an "apparent temperature", or "feels-like temperature", which indicates the human perception of temperature.

WBGT is measured with three different thermometers: dry-bulb, wet-bulb, and black-globe thermometers [9]. A dry-bulb thermometer measures the actual air temperature. A wet-bulb thermometer is a thermometer wrapped in a water-moisturized cloth. It behaves differently from a dry-bulb thermometer by taking into account humidity and wind. The less humid the air is, the faster the water will evaporate, and the faster water evaporates, the lower the thermometer's temperature will be relative to air temperature. A black globe thermometer is a thermometer inside a black globe. The black surface absorbs solar heat, and the surface temperature is affected by wind.

WBGT is calculated as a weighted mean of the data inputs from these thermometers: dry-bulb temperature (T_d), wet-bulb temperature (T_w) and black-globe temperature (T_g):

$$WBGT = 0.7 * T_w + 0.2 * T_g + 0.1 * T_d$$

If T_d, T_w and T_g are measured in Fahrenheit (F), WBGT is computed in F. If they are in Celsius (C), WBGT is computed in C.

As this equation shows, WBGT places a very high weight for wet-bulb temperature (T_w), compared to dry-bulb temperature (T_d), because it is intended to emphasize the large impact that humidity has on the body's ability to sweat and release heat. Although many people look at air temperature to determine the safety of being active outside, this can be misleading. Even when the air temperature is lower it can still be dangerous if the humidity is extremely high and there is no wind. WBGT quantifies this risk effectively.

As a result, professional, national, and state athletic associations have accepted WBGT as the primary means of determining the appropriate temperatures for hot weather activities. For example, the United States Tennis Association sets WBGT-based heat policies for junior singles, wheelchair singles, women's open singles, and men's open singles matches in the US Open

Championships [10]. The United States Soccer Federation's player health and safety program, called Recognize to Recover, provides WBGT-based heat safety guidelines too [11].

X.2.3 WBGT-based Heat Policies for High School Athletes

The National Athletic Trainers' Association (NATA), which organizes the largest community of high school athletic trainers in the US, released a position statement about heat-related illnesses in 2015 [12]. It uses WBGT as a means of measuring environmental risk factors and offers an example WBGT-based safety policy. It also points out that a "one size fits all" heat policy does not work across different geographical regions in the US.

By analyzing regional variations in acclimatization to heat based on climatology research findings, Grundstein et al. define three regions in the US (Fig. 5) and propose a WBGT-based heat policy for each region (Fig. 6) [13]. As shown in Fig. 5, northern regions (Category 1) have lower WBGT thresholds for activity adjustment than other regions (Categories 2 and 3) because athletes in the North are less acclimatized to heat than in other regions.

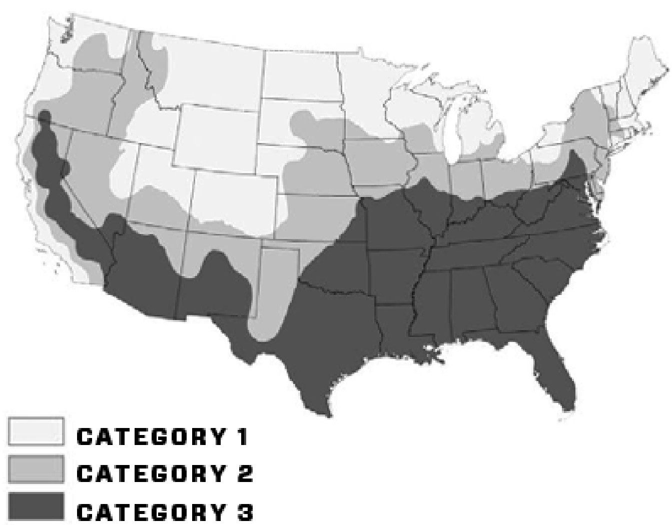

Fig. 5: Regional Categories based on Acclimatization to Heat. Excerpt from [13].

WBGT by Region (F)			Activity Adjustment Guideline	Alert Level
Region 1	Region 2	Region 3		
<= 76.0	<= 79.7	<= 82.0	Normal activities. At least 3 separate 3-min breaks each hour.	Good
76.1-81.0	79.8-84.7	82.1-87.0	Use discretion for intense or prolonged exercise. At least 3 separate 4-min breaks each hour.	Cautious
81.1-84.0	84.8-87.7	87.1-90.0	Max 2 hrs of practice. 4+ separate 4-min breaks each hr.	Risky
84.1-86.0	87.8-89.7	90.1-92.0	Max 1 hr of practice. No conditioning activities. 20-min breaks distributed throughout the hour.	High Risk
>= 86.1	>= 89.8	>=92.1	No outdoor workouts. Delay practice/competitions until a cooler WBGT is reached.	Extreme

Fig. 6: WBGT-based Activity Adjustment in each Regional Category based on [13]

Currently, this is the most widely-used heat policy for high school athletes. It is recommended by the National Federation of State High School Associations (NFHS), which writes the rules of competition for most high school sports and activities in the US [14, 15]. Most high schools in the US (more than 18,000 high schools) belong to NFHS through their state's high school associations. For example, the Massachusetts Interscholastic Athletic Association (MIAA) is a member of NFHS, and it consists of more than 370 high schools in Massachusetts. Following NFHS' recommendation, MIAA sponsors activities and competitions in 33 sports based on the Category 1 WBGT thresholds in Fig. 6 [16, 17].

In this project, AlertAthletes downloads the local WBGT forecast from NOAA and identifies one of five alert levels based on the forecast and regional category.

X.2.4 Ultraviolet Radiation

In addition to heat-related illnesses, sunburn is another environmental threat for outdoor athletes in direct sunlight. It is caused by too much exposure to ultraviolet (UV) light. There are three types of UV rays: UVA, UVB, and UVC. UVC rays are the most dangerous type of UV radiation, but they are mostly absorbed by Earth's ozone layer [18]. UVA and UVB rays reach the Earth's surface, and they are harmful to the body. UVA rays have a longer wavelength than UVB rays, which allows them to penetrate deeper into the skin, causing skin aging and inflammation that can lead to skin cancer. UVB does not penetrate as deeply as UVA, but it damages skin cells and mutates their DNA, which can lead to melanoma and other types of skin cancer [19, 20]. UV is said to be the strongest cancer-inducing substance to humans, even stronger than cigarette smoke [20].

UV rays not only damage the skin, but also are harmful to the eyes. They penetrate eye tissues easily and increase the risk of eye problems [18]. The longer the eyes are exposed to UV rays, there is a greater risk of developing cataract or eye cancer later in life [21].

Effective ways to reduce these risks include covering skin with clothing, wearing the right sunglasses, and wearing a hat. Of course, it is absolutely necessary to wear the right sunscreen as well, especially for athletes.

X.2.5 Ultraviolet Index (UVI) and UVI-based Protection Measures

Ultraviolet index (UVI) is a numerical index that quantifies the expected risk of UV exposure on a scale from 1 (low) to 11+ (extremely high) [22]. It is used to define standard sun protection measures. Fig. 7 shows the UVI-based measures by the US Environmental Protection Agency (EPA).

UVI	Sun Protection Guideline	Exposure Level
1-2	You can safely enjoy being outside. Wear sunglasses on bright days. If you burn easily, cover up and use sunscreen SPF 15+.	Low
3-5	Take precautions, such as wearing a hat and sunglasses and using sunscreen SPF 30+. Stay in shade during midday hours.	Moderate
6-7	Protection against sunburn is needed. Cover up and use sunscreen SPF 50+. Seek shade during midday hours.	High
8-10	Take extra precautions. Unprotected skin will be damaged and can burn quickly. A shirt, hat and sunscreen are a must. Be sure to seek shade during midday hours.	Very High
11+	Take all precautions. Unprotected skin can burn in minutes. A shirt, hat and sunscreen are a must. Be sure to seek shade during midday hours.	Extreme

Fig. 7: EPA’s Sun Protection Measures based on UVI

In this project, AlertAthletes downloads the local UVI forecast from OpenWeatherMap and identifies one of five exposure levels.

X.2.6 Rain and Lightning

AlertAthletes considers rain and lightning as extra environmental threats for athletes because they are key factors in safety protocols for outdoor sports. Some sports immediately stop their events at the onset of rain, such as baseball, softball, tennis, and golf. This is because even slightly wet conditions can affect athletes’ safety and performance. For example, tennis hard courts become extremely slippery in wet conditions and also ruin the tennis balls, making them heavier and less bouncy. The slippery courts and irregular ball bounce have significant impacts on players' safety and performance.

Lightning is a more serious threat for any sport. The National Weather Service reports that about 30 people are killed by lightning each year and hundreds more are injured, including lasting neurological injuries. About two thirds of the deaths are associated with outdoor recreational activities [23]. Therefore, many sports reschedule events for the forecast of lightning, and most events postpone about 30 minutes at any sight of lighting [24].

In this project, AlertAthletes downloads the local forecast of rain and lightning from OpenWeatherMap.

X.3 Hardware

This section describes how to prepare and set up hardware components to build AlertAthletes.

X.3.1 Preparing Hardware Components

AlertAthletes is built with an RP2040 microcontroller (Raspberry Pi Pico W) and its peripheral components.

- Pimoroni Badger 2040W (1x): This is equipped with an RP2040 microcontroller (Raspberry Pi Pico W), a 2 MB flash memory, a WiFi module, and a real-time clock (RTC). It has a Micro-USB port, five buttons, a black-and-white e-ink display (2.9 inches, 296 x 128 pixels), and a 2-pin JST-PH connector for a battery (input voltage range: 2.7V - 5.5V). The device weighs 27 grams (0.9 oz). Its dimensions are 86 x 49 mm. Available at Pimoroni [25], Pi Shop [26] and DigiKey [27].

- Type-A to Type-C USB cable (1x): This is used to connect a Badger to a laptop/desktop computer where software development takes place.

- Lithium polymer (LiPo) battery (1x): This is used to power a Badger. Any LiPo batteries work as far as their output voltage is 3.7V. This project uses the capacity of 105 mAh (Fig. 8) because it is one of the smallest capacities on the market (3 grams; 0.1 oz), but any other capacities are fine such as 350 mAh (7 grams; 0.2 oz) and 420 mAh (9 grams; 0.3 oz). Available at Adafruit [28].

- LiPo Charger (1x): This is used to charge a LiPo battery. Available at Pimoroni [25] and Adafruit [28].

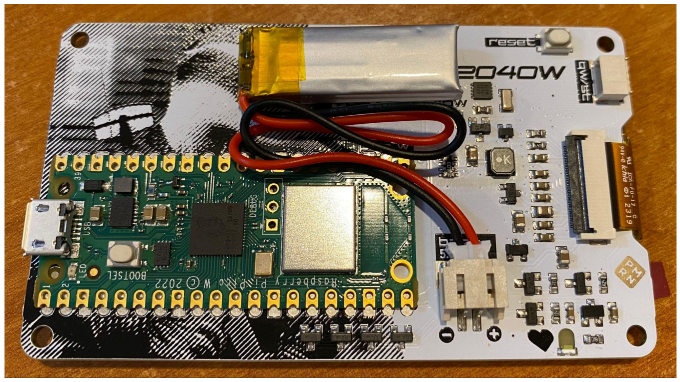

Fig. 8: Backside of a Badger 2040W. It is connected to
a 105 mAh LiPo Battery with Red and Black Wires.
A Green Rectangle Board is an RP2040 (Raspberry Pi Pico).

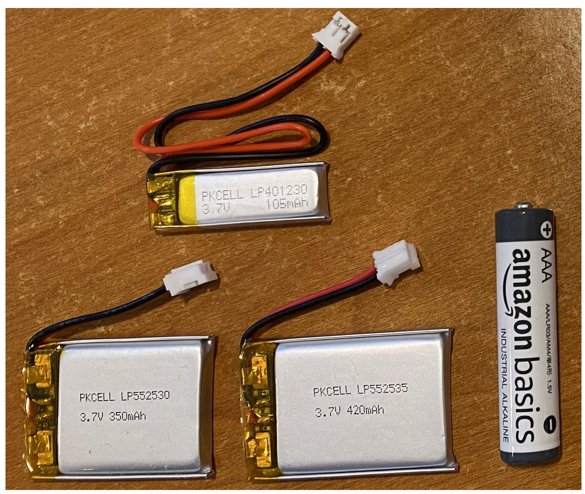

Fig. 9: 105, 350 and 420 mAh LiPo Batteries

Plug a USB cable to the Badger's USB port and connect the cable to the laptop/desktop computer. This turns it on and boots it. You can reboot it by pressing the "reset" button on the backside of the Badger.

X.3.2 Installing MicroPython Firmware

Pimoroni integrates MicroPython firmware with all required drivers as a single package called BadgerOS. It is pre-installed in a Badger; you do not have to install it by yourself. If you would like to install an updated version of BadgerOS, download it from the "releases" section of [29].

This project uses Thonny [30] for coding and using the REPL prompt, but any MicroPython-compatible tools should work as well. The libraries available in the MicroPython firmware can be printed on the REPL prompt in CircuitPython by running **`help("module")`**.

X.3.3 Configuring WiFi Credentials

Badger has a WiFi module, and this project uses it to download environmental forecasts. To set up WiFi credentials, find **`WIFI_CONFIG.py`** in your MicroPython file system and add the following three lines.

```
SSID = "abc"
PSK = "xyz"
COUNTRY = "US"
```

Replace **`abc`** with your WiFi's name and **`xyz`** with your WiFi's password. These settings allow your device to connect to the WiFi.

Run the following code to make sure that your device is online.

```
import badger2040
badger = badger2040.Badger2040()
badger.connect()
```

The code prints a certain IP address, such as 192.168…, and shows it on the e-ink display if everything goes well.

X.4 Software

AlertAthletes runs the following MicroPython code, which is available as **`main.py`** in the **`code`** folder in [31]. When a Badger boots, MicroPython looks for **`main.py`** in its file system and runs the code automatically. Place this code, **`noaa_wbgt.py`**, **`noaa.py`**, **`openweather_extractors.py`**, **`openweather.py`**, **`unoaa_wbgt.py`**, **`utils.py`**, and **`weather.py`** in the top/root folder of your MicroPython file system. All these source files are available at [31].

```
import badger2040
from machine import Pin
from utils import displayEnvInfo, displayWbgtSuggestions, displayUviSuggestions

LAT =
LON =
WEATHER_API_KEY = ""

DEEP_SLEEP_INTERVAL = 5   # in minutes
LED_BRIGHTNESS      = 128 # [0,255]
```

```
display = badger2040.Badger2040()
display.led(LED_BRIGHTNESS)

# If Button A pressed on battery
if badger2040.pressed_to_wake(badger2040.BUTTON_A):
    displayWbgtSuggestions(display)
    badger2040.sleep_for(DEEP_SLEEP_INTERVAL)

# If Button C pressed on battery
elif badger2040.pressed_to_wake(badger2040.BUTTON_C):
    displayUviSuggestions(display)
    badger2040.sleep_for(DEEP_SLEEP_INTERVAL)

# If Button Up or Down pressed on battery
elif badger2040.pressed_to_wake(badger2040.BUTTON_UP) or \
     badger2040.pressed_to_wake(badger2040.BUTTON_DOWN):
    displayEnvInfo(display, LAT, LON, WEATHER_API_KEY, useWifi=False)
    badger2040.sleep_for(DEEP_SLEEP_INTERVAL)

# If Button B pressed on battery
elif badger2040.pressed_to_wake(badger2040.BUTTON_B):
    displayEnvInfo(display, LAT, LON, WEATHER_API_KEY)
    badger2040.sleep_for(DEEP_SLEEP_INTERVAL)

while True:
    print("Currently powered by USB")
    if display.pressed(badger2040.BUTTON_A):
        displayWbgtSuggestions(display)
    elif display.pressed(badger2040.BUTTON_B):
        displayEnvInfo(display, LAT, LON, WEATHER_API_KEY)
    elif display.pressed(badger2040.BUTTON_C):
        displayUviSuggestions(display)
    elif display.pressed(badger2040.BUTTON_UP) or display.pressed(badger2040.BUTTON_DOWN):
        displayEnvInfo(display, LAT, LON, WEATHER_API_KEY, useWifi=False)
    else:
        displayEnvInfo(display, LAT, LON, WEATHER_API_KEY)
    badger2040.sleep_for(DEEP_SLEEP_INTERVAL)
```

To run this code properly, three red lines in the code need to be completed as follows:

- Find the latitude and longitude of a location where the device is used, and specify them in the constants **`LAT`** and **`LON`**.
- Obtain an API key for the One Call API 3.0 of OpenWeatherMap [32], and specify it in the constant **`WEATHER_API_KEY`**.

`main.py` instructs what AlertAthletes does and how it triggers screen transitions. When the device boots, the **`displayEnvInfo()`** function in **`utils.py`** is called to download environmental forecasts and display them on the e-ink display (Fig. 2). If the button B is pressed, AlertAthletes downloads forecasts again and refreshes the screen with the new forecasts. If the button A is pressed, AlertAthletes displays an activity adjustment guideline based on the current WBGT (Fig. 3). If the button C is pressed, it displays a sun protection guideline based on the current UVI (Fig. 4). If the Up or Down button is pressed, it re-loads the main forecast screen.

AlertAthletes has about 660 lines of code in total. Their total size is 23.5 KB. Libraries consume 32 KB. The total size of 55.5 KB is small enough for the 2 MB flash memory space in Badger 2040W.

X.4.1 Operating Deep Sleep Cycles

Once AlertAthletes displays a screen or completes a screen transition, it calls the `badger2040.sleep_for()` function to move into the "deep sleep" mode. The default sleep period is five minutes. When the device is on battery, `sleep_for()` turns off the microcontroller, runs only the RTC to reduce power consumption, and wakes up the microcontroller after a sleep period. Note that the e-ink display does not require power during the sleep period. Once woken up, the microcontroller runs `main.py`.

X.4.2 Downloading Environmental Forecasts

AlertAthletes downloads WBGT forecasts from the National Digital Forecast Database (NDFD). NDFD is developed by NOAA for the National Weather Service [33]. NDFD provides a REST API that returns XML data in the Digital Weather Markup Language (DWML). AlertAthletes uses the `noaa.getWbgt()` function to extract the latest hourly forecast from the downloaded XML data.

AlertAthletes downloads UVI, precipitation and lightning forecasts from OpenWeatherMap. OpenWeatherMap provides a REST API that returns JSON data. AlertAthletes calls the `weather.getOwmData()` function to extract the latest hourly forecast from the downloaded JSON data. The chance of rain is expressed in percentage, and the chance of lightning is indicated as "Yes" or "No" (Fig. 2). "Yes" means that a thunderstorm is expected within an hour.

X.4.3 Displaying Environmental Forecasts

AlertAthletes calls the `utils.displayEnvInfo()` function to display the current forecasts in the main screen (Fig. 2). It calls `utils.displayWbgtSuggestions()` and `utils.displayUviSuggestions()` to display a WBGT-based activity adjustment guideline and a UVI-based sun protection guideline, respectively. These functions rely on the PicoGraphics API, which is a combination of an e-ink display driver and MicroPython convenience functions. It is readily available in BadgerOS [29].

X.4.4 Adjusting Battery Life

With the battery fully charged (105 mAh), AlertAthletes can operate for about 22 hours with its default settings. This is long enough for a sports practice/event. It takes 30 minutes to recharge the capacity of 105 mAh with a LiPo charger.

This battery life can be extended by adjusting the deep sleep period from the default five minutes. Change the **`DEEP_SLEEP_INTERVAL`** constant in **`main.py`**. For example, the battery life can be extended to 48 hours with the 11-minute sleep period.

X.5 Future Work

AlertAthlete can be improved in several ways. For example, it would be more versatile if it can display more environmental parameters. The air quality index (AQI) can be useful, especially in populated areas, to make sure it is safe to have physical activity outside. AQI is measured from 0 to 300+, and usually if the index is under 50, it is safe. As the value increases, more breaks and less intense activity is recommended [34]. This would especially help any athletes with asthma because they are more sensitive to air quality. Similar to UVI, EPA provides activity guidelines based on the condition of air quality [34].

It would also be helpful if AlertAthlete can display activity schedules. Schedule data could be fetched from a calendar app. This way, AlertAthlete can work as a reminder device for matches/games, practice sessions, gym visits, and workout plans.

Another improvement is to adjust NOAA's WBGT forecasts based on where AlertAthletes is used. Although the forecasts are carefully calculated in NDFD [33], they can be very different from the actual WBGT on particular ground surfaces. For example, in tennis, hard courts are the most common surface type, which is made of concrete and/or asphalt. Both materials absorb heat more and raise air temperature more than natural surfaces [7]. According to recent research findings [35], WBGT measurements on tennis hard courts are higher than a standard WBGT estimate. The difference/error increases proportionally as the estimated WBGT increases. It is nearly 1°C (1.8°F) when the estimated WBGT is higher than 87.8°F (31°C). Therefore, it would make sense for AlertAthletes to adjust NOAA's forecast when used for tennis practices or matches on hard courts.

X.6 Conclusion

AlertAthlete monitors environmental conditions and alerts outdoor athletes to potential threats to help them take necessary precautions early, prevent accidents, and perform at their best. Built with a battery-operated RP2040 microcontroller, AlertAthlete tracks WBGT, UVI, precipitation and lightning forecasts, and displays them along with suggested precautions such as taking a shade break and putting on extra sunscreen. Its MicroPython code is available at [31].

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