Pedal-Powered Smart Bike

ECE 445 Design Document

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1 Introduction

1.1 Objective

With rising population rates, it is without a doubt that cities across the globe will increase in population density. With over [1] 1.7 billion people living in cities in 2018, estimated to reach 2.5 billion by 2050, one can only imagine how this might further increase traffic congestion resulting in longer commute times. As a result, many individuals are opting for alternative means of commute. [2] In fact, it is estimated that the amount of individuals who use a bike to commute to work will double by 2022. Outside of commuting, biking also serves as an excellent form of exercise. [3] Cycling is great for losing weight, cardiovascular training, as well as building up muscle. [4] Cycling can even benefit an individual's mental health, improving mood, sleep, and creative thinking! On the other hand, using a bike as a primary means of transport may also be risky for a cycler, especially in large, densely populated cities. We are even seeing cyclist-related accidents increase as time goes on. [5] With over 2% of motor vehicle crash deaths, cyclists still represent a significant amount of potentially avoidable accidents every year. [6] In 2018, there were over 857 cyclist deaths due to collisions with automobiles, representing over a 6% increase in deaths from the year prior.

Our project seeks to solve multiple issues that bicyclists face on a daily basis. We plan on creating a multi-tool for bicycles dealing with three main issues: navigation, exercise, and safety. Using a microcontroller, motor, RGB screen, and various other components, we will completely power our multi-tool through user pedalling and a battery. The RGB screen will be used to display important information for the user with regards to their navigation and exercise. A GPS module will inform the user of their heading and current location. Information captured from both the motor and the GPS will capture the user's speed, distance, and exerted power. Finally, an ambient light sensor and buttons will allow the user to be visible in low light conditions as well as inform other drivers and cyclists of their intent to turn.

1.2 Background

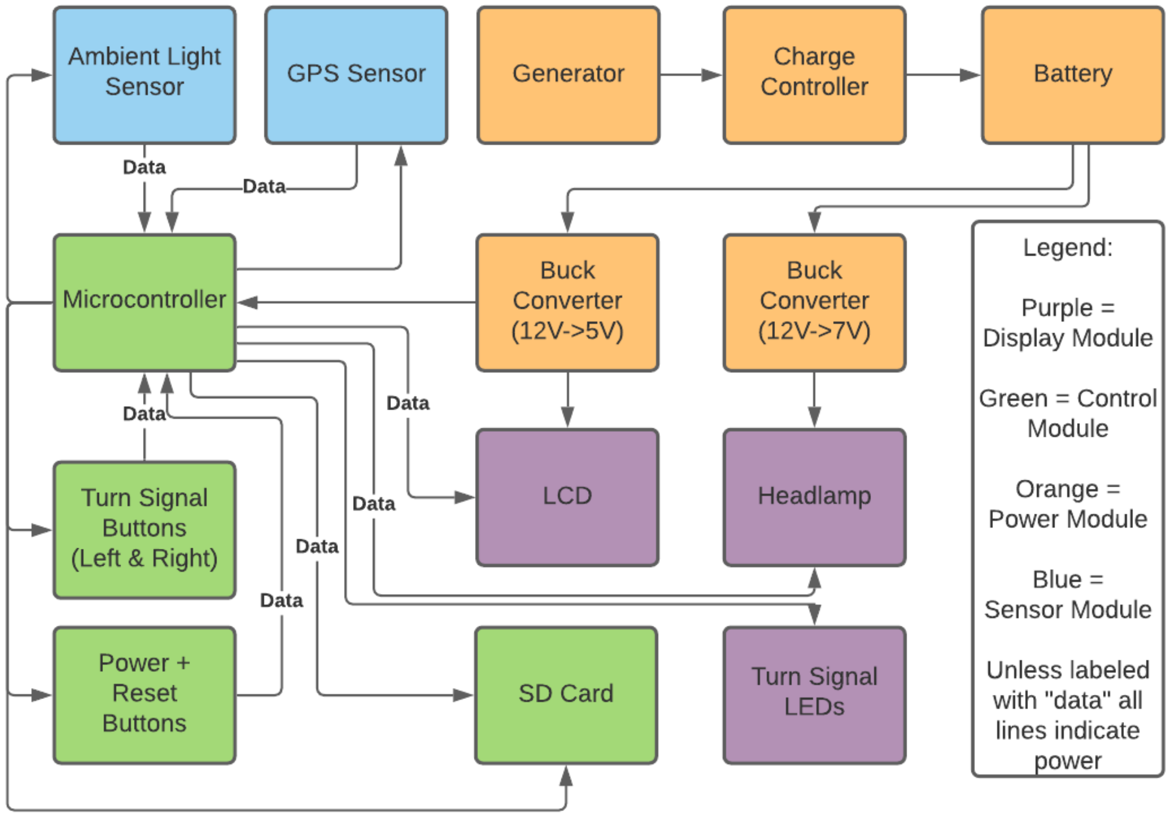
While there have been a couple attempts to emulate similar experiences, none offer a truly offline experience that allows an individual to discount from his/her devices and fully embrace the outdoors. SmartHalo [8] is a brand that has attempted something similar, yet falls short in aspects that our device allows. Offering certain similar features such as GPS location and light signaling, SmartHalo does not offer a pixel based interface, exercise statistics, and operates off of a battery instead of being powered by user pedaling. Additionally, it encourages the user to connect their phone to the device and the bright, multi-colored display may be distracting to some.

1.3 Visual Aid

1.4 High Level Requirements

1. Entire device is powered by pedaling on behalf of the user
2. Device interfaces with GPS module to provide valuable exercise and location metrics to the user
3. Physical buttons used to control turn signaling and turn the device on or off

2 Design



2.1 Power Supply

The power supply consists of a system of a motor charging a battery aided by a controller for protection and a mechanical system for rotation. All that will be triggered by the user's pedaling motion.

2.1.1 Motor

The motor will be attached to the back frame of the bike using a hinge system and will be hanging right over the back-wheel tyre. Its brush has an 11-teeth sprocket for a #25 chain. It will turn as the wheel turns using a rotation system we will describe next. The motor is rated at 50 Watts with an RPM rate of 3500 at 24Volts and an efficiency of 79%. It has a diameter of 4.0in and a length of 4.3in. It will supply DC power to the battery.

Requirement	Verification
Needs to turn easily enough and not create too much drag.	Test the motor's resistance to turning as soon as possible at the machine shop and change position of motor to minimize resistance.
Must turn enough times per minute to generate enough power. Have a big enough ratio of turning gear diameter to motor brush diameter to produce as high a voltage (~14V)	Use the wheel as the trigger to turn the sprocket. Use a voltmeter to test how much voltage is output.

2.1.2 Rotation System

The rotation system will be composed of an intermediary piece composed of a small wheel (~1in diameter) and a #25chain-compatible sprocket. The small wheel will be in contact with the bike tyre and turn at the same speed and thus higher rate. It will in turn, rotate the sprocket that will turn the motor brush's sprocket as they will be intertwined sprocket-to-sprocket.

Requirement	Verification
Needs to make the motor turn easily enough and avoid too much resistance.	Testing at the machine shop. Mainly with Gregg's supervision and experience

2.1.3 Charge Controller

The charge controller's input will be connected to the motor and will output to the battery. It will ensure the battery does not over charge and that the voltage applied to is not excessive since the motor can output from 12V to 24V. The charge controller also acts as diode ensuring the current only flows in a single direction. That is, from the motor to the battery.

Requirement	Verification
Should act as a diode.	Place it in a simple circuit between the battery and the motor. If the motor turns, then the controller is dysfunctional.
Should prevent the battery from overcharging.	Use a voltmeter to see monitor voltage at the output of the controller while pedalling. (Controller might have a built-in multimeter with a display.)

2.1.4 Battery

The battery we have is a 8V, 2Ah Acid Lead battery. It is a rechargeable battery and will be connected to the charge controller from which its charge will come. It will in turn feed the rest of the system (control and GPS modules, sensors, lights).

Requirement	Verification
Needs to make the motor turn easily enough and avoid too much resistance.	Testing at the machine shop. Mainly with Gregg's supervision and experience

2.1.5 Buck Converters

We will use at least two buck converters between the battery and the circuit's components. These have a role of stepping down the voltage from the battery to the different peripherals depending on their nominal voltages. Our microcontroller has a nominal voltage of 5V, the GPS sensor has a Vcc of 3.6V and the ambient light sensor will range from 3.3V to 5V. The chosen LCD Display has a nominal voltage of 5V. Our rear LEDs will also have voltages ranging from 3V to 5V and our headlight LEDs might range from 5V to 8V. The ambient light sensor can be powered by the AVR microcontroller through the AVCC port. That is the supply voltage for the Port A which has an A/D Converter capability. There will be one buck converter for the Microcontroller, one for the headlights, one for the three rear lights and one for the GPS module (may be the same as for AVR).

Requirement	Verification
Should step-down the voltages as needed.	Use multimeters to test them.

2.2 Control Module

2.2.1 ATMEGA328 AVR Controller

In order to stream serial data from our various sensors for the processing of exercise analytics, we plan on using an AVR Controller, specifically the Microchip Technology ATMEGA328-PU. With a 28 pin configuration as well as 32 KB of flash program memory, this microcontroller will allow us to write our own programs and interface with our hardware sensors. The ATMEGA328 supports communication with multiple digital peripherals with its UART, SPI, and I2C ports. The AVR controller also operates from 1.8-5.5. Our microcontroller also has 2 KB of SRAM which is necessary to drive a video buffer to our LCD display.

Requirement	Verification
Can interface with our LCD Display	The LCD display supports both SPI or I2C connections, supported by our microcontroller. Display requires an SRAM of at least 1 KBfor a video buffer, our controller has 2 KB.
Can interface with our GPS module	GPS module supports UART connections, supported by our microcontroller
Can interface with our SD Card	Using FatFs library with our AVR, we can write data blocks to our SD card

2.2.2 SD Card

We plan on using our AVR controller to write GPS sensor data onto our SD card in order to capture data respective for the entire trip. By ensuring that we are using an SDC, we can actually interface with our microcontroller in order to write data. We choose to use an SDC card because of more available pins and because it is more currently supported. While the size of the SD card is somewhat arbitrary since we will only be encoding unparsed sensor data kept as Strings, a good minimum we are looking for is at least 4 GB, classifying our SD card as FAT32 storage. Most standard SD cards support 2.7-5V. Anywhere past 5V will destroy the SD card.

Requirement	Verification
FAT32 Requirement	Forcing a storage minimum of at least 4 GB qualifies as FAT32
Minimized write speed throttle	As we increase our size, our write speeds will decrease, for this we stay at 4 GB since it's the minimum size to qualify for FAT32
Interface with Microncontroller	We need to use one of the 2 available SPI communication ports with the AVR microcontroller, using FatFs to write data blocks

2.2.3 USB Programmer

We will need to use a standard USBasp programmer in order to program our AVR microcontroller. By connecting to GND and 3 pins on our microcontroller, we can write programs in a variety of languages (C/C++/Assembly) in order to receive data from our GPS sensor and display it on our OLED display. Since this is a fairly standard and proprietary device, there aren't any specific requirements.

2.3 GPS Module

The GPS module we've decided to use is the uBlox NEO-6M GPS Module. A very simple sensor, we only require power, a ground connection, and a pin available on our microcontroller to receive our transmitted data. The GPS module expects power of 2.7-5V, much like the other components of our circuit. The operating current of our GPS module is 45 mA. Data is captured as a String, so we need to ensure that the data transfer rate of the GPS module is high enough.

Requirement	Verification
Transfer Speeds fast enough	With a baud rate of 9600, we can transfer 9600 bits per second through our UART serial port
Relevant Data received	The GPS module gives time, latitude, longitude, altitude, heading, and other metadata available in a String. Our AVR can then process this data with simple physics equations to get more relevant data for the user.

2.4 Sensor and Lighting

Our project will equip the bicycle with the necessary lights to ensure the biker's safety at night. This consists of an ambient light sensor that will determine the lighting of the headlight and rear light as well as right and left turn lights controlled via buttons at the user's fingertips.

2.4.1 Ambient Light Sensor

Ambient light sensors require 3.3V to 5V of supply voltage. Since this is an analog sensor output sensor, it will be powered through the AVCC pin of the AVR ATMega Microcontroller we are using and will output data to a pin of Port A of the AVR. This is because the Port A of the microcontroller has the feature of serving as an analog input to the ADC of the microcontroller. That is, its Analog to Digital Converter. The code will determine at which specific input value received from the sensor do we switch the LEDs ON or OFF. The goal is to use the analog light sensor as a data input to control the LEDs and switch them on when it is dark outside. The output wire from the microcontroller carrying the command data regarding the sensor's input will be connected to the LEDs using transistor switches.

Requirement	Verification
Must communicate real time information to microcontroller	Connect it to the microcontroller with a simple code and turn lights on and off to see how fast the sensor reacts.

2.4.2 Transistor Switches

The transistors will be used as switches between the buck converters and the powered peripherals using the corresponding output data of the microcontroller as the control pin of the switch. That way we would only power the LEDs depending on the code of the microcontroller. If not, they will constantly receive power from the battery and stay on the whole time.

Requirement	Verification
Must support the current and voltage applied to it and output adequate voltage to peripheral component	Buy a corresponding transistor and test it by applying the same voltages as in the circuit to its pins. Use a voltmeter/multimeter to check the output.

2.4.3 Headlight and Rear Light LEDs

The headlights will be LEDs emitting a white light strong enough to illuminate the biker's way for at least 5 meters ahead. This requires 100-300 LED lumens which does not exceed 4W power which our battery produces easily. The rear light is the same but needs even less energy and brightness since it is red and only needs to be perceivable by vehicles behind the bicycle.

Requirement	Verification
Provide the needed illumination to ensure user safety at night.	Power the LEDs at night on a dark street to check efficiency.

2.4.4 Turn Lights

The turn lights will be positioned on each side of the bike at the rear. They will also be controlled via the microcontroller and transistor switches. However, these will receive their control data from buttons instead of the ambient light sensor that way they can be used throughout the day.

Requirement	Verification
Lights must blink at an adequate rate.	Test the lights by coding the blinking pattern and commanding them to see if they can blink fast enough.

2.5 Buttons

Our design requires 4 high-level control buttons. These are the ON/OFF button, which turns off the whole circuit, the Reset button, which resets the LCD Display, and two turn buttons, one for each side to control the turn lights described above.

2.5.1 ON/OFF Button

The ON/OFF Button will be connecting the battery to the buck converters acting as a general switch for the entire circuit. It will function as a regular switch. It will be big in size and will be placed in a convenient place for the user, either at the front or at the center of the bike frame.

Requirement	Verification
Button must turn the whole circuit ON or OFF with no exception.	Get a regular electromechanical switch to avoid coding requirements and bugs. Test is in any circuit.

2.5.2 Reset Button

The Reset button will be connected to the microcontroller. Once pressed, the microcontroller will react by sending an output signal to the LCD display which will reset the data on the screen. This is to be used by the user when starting a new trip. For instance, it will reset the time of trip and distance travelled to 0. This will be a push button.

Requirement	Verification
Button must reset data once and not affect the circuit until pushed again.	Test buttons in a simple circuit with an LED and voltage supply where the LED turns on only when push-button is pressed. Code must be tested so that the reset state happens only while the button is pressed.

2.5.3 Turn- Light Buttons

These two buttons will be placed near the handles of the bike, one on each side. They will be big to make it convenient for the biker to use them. As soon as one of them is pressed/pushed, the microcontroller will output alternating HIGH and LOW signals to the corresponding light's switch with 1/4 second delays. This will make the corresponding turn light blink to inform the vehicles behind the bicycle which way the biker will turn at the next crossing. The lights will only be turned off when their corresponding button is pressed again.

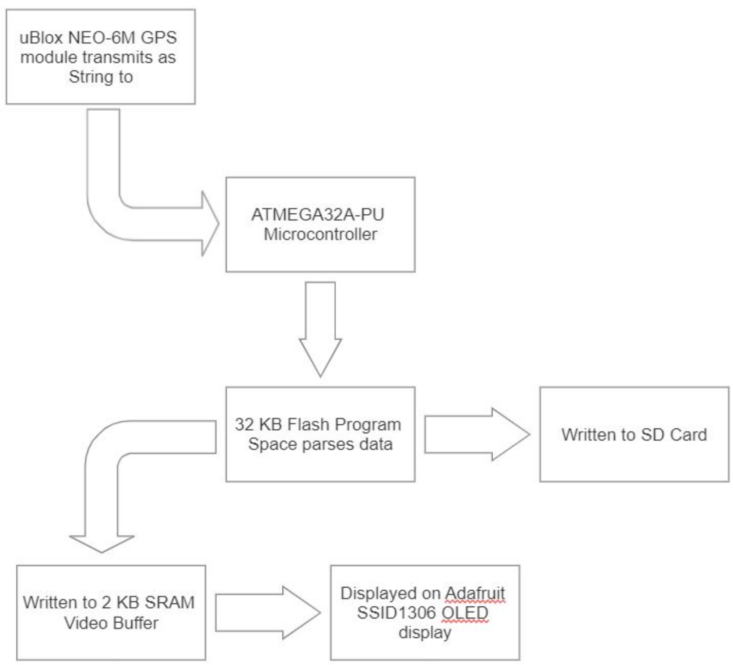
Requirement	Verification
Buttons must send data adequately.	Test buttons in a simple circuit with an LED and voltage supply.

2.6 LCD Display

For our LCD display, we have decided to go with the Adafruit Monochrome 1.3" 128x64 OLED display. The driver chip being used is the SSD1306, which commonly supports both SPI and I2C communication. As both are supported by our microcontroller, we found this to be the best option. As our microcontroller has a 2 KB SRAM, we can actually push a video buffer which requires at least 1 KB SRAM from our microcontroller. We opted for the use of monochrome, since we are only displaying text for the user. This display requires 3.3-5V and will generate around 40mA of current.

Requirement	Verification
Microcontroller buffer large enough	We need at least 1 KB of SRAM for a video buffer, where our microcontroller are 2 KB
Microcontroller communication	Defaulting to I2C (industry standard for some displays), the display can even be modified to allow for SPI, both of which supported by microcontroller

2.9 Software



2.9.1 GPS Module Interface

As we are planning on processing the GPS module data in order to provide useful exercise and location statistics to our user, we will have to interface our GPS module with our AVR microcontroller. Fortunately, there is only one serialized TX output coming from our NEO-6M GPS module which we assign to our PD0 pin of our microcontroller. Our GPS data comes in as a serialized String, such as with the following example:

```
$GPGGA,141848.00,2237.63306,N,08820.86316,E,1,03,2.56,1.9,M,-54.2,M,,*74
```

We are given a String separated by commas with the first, “GPGGA,” referring to “Global Positioning System Fix Data.” The following value is a timestamp in -GMT, useful in providing the current time to the user. The next four values refer to the latitude and longitude, as well as their respective hemispheres, providing geopositional data to the user. When our data streams to our AVR microcontroller, we can use both the change in timestamps and change of distance between two consecutive points of GPS measurement data to calculate speed. Based on the change in direction, we can also calculate the heading that the user is directed towards. There are also many libraries that can provide even more information to allow for more accurate measurements. The benefit of using an ATMEGA328 is that we can use simple C/C++ code to create all of these calculations.

2.9.2 LCD Display Interface

Utilizing the PC4 and PC5 corresponding to the SDA and SCL pins for our Adafruit display, we can easily connect our AVR microcontroller via IC2. The process of creating a display buffer becomes relatively simplified by extending various free to use libraries that enable us to use simple write commands to display anything we would like on our monochrome display. By creating an always-on display template, we can simply create fields which are dynamically updated based on data read and processed from the GPS module and microcontroller which is stored onto flash program memory. Adafruit provides an SSD1306 library on Github which is accessible by Atmel Studio 7, our preferred IDE for writing code for our ATMEGA328.

2.10 Tolerance Analysis

The most challenging part of our project is arguably the power supply block, specifically the power generation using the motor. In fact, motors react by producing a resistance when they are turned. The faster they are made to turn, the bigger the drag and the harder it is to pedal. Done incorrectly, it can become impossible to turn. If that were to happen, our project would fail completely since the cornerstone of the project is its pedal-powered aspect. To elucidate this issue, we must refer to our manufacturer’s website from where we have ordered the motor [10] . The chart on the website for our specific motor shows a clear decrease in the power produced by the motor as the torque exerted on it increases [11] .The efficiency has a max of 79% and we observe that it slowly decreases after the torque exerted on the motor exceeds 0.6N-m. We can make a simple calculation to get the average torque exerted on the pedal at the hub. That is ***2 x mass x g x π x radius***, which is a pedal distance from the hub of 15-20cm on average and an average person’s mass of 65kg. We can reduce the mass value given that we are not standing on the pedals. The torque value is therefore **2*50*9.81*3.14*0.17 = 523.7 N-m**. That it is a huge value and is not even accounted for in the chart we have. However, it is not a problem because we will not be exerting that much torque on the motor. The motor will be hanging above the back wheel and it’s brush will be turned by a small system consisting of a wheel that will turn at the same rate as the tire due to friction force and another sprocket attached to it will be turning the brush motor's sprocket therefore exerting an efficient torque on the motor and at a good enough speed since the ratio of the wheel to that of the motor's sprocket is very big, That means that for every turn of the wheel, the motor will turn multiple times. The exact ratio is as follows: A bike wheel is 23in in diameter and the 11-tooth #25 sprocket is 1.002in in diameter. That yields a ratio of 23/1.002 = 23. So for every wheel turn, the motor will turn 23 times.

2.11 COVID-19 Contingency Plan

In the event that COVID-19 forces us to return to online classes before the project is completed, we will need to shift the way that we approach our project. That said, the degree to which the project needs to shift will be contingent on which milestones are achieved prior to the time that we are sent home. Given that our project is centered around the proper application of a motor attached to our bike, the central milestone will be properly installing the motor and battery on the bike with the help of the machine shop.

Should we fail to reach this mark prior to being sent home, we will need to change the design to a proof of concept more so than a finished product. Meaning, mounting the motor on the bike will have to be scrapped and we will have to create a rig which allows for some stationary pedaling. From here, we should be able to build out the same project and test most functionality in a similar way. Lights can still be tested, buttons should still work as intended, and the display should still have all functionality. The biggest issue will be whether or not the gps module functions and for this we could still test it by charging the battery sufficiently and then demonstrating its use in a car.

Conversely, should we successfully mount the motor and battery prior to being sent home, we should be able to continue the project as planned. One of our teammates, the one who owns the bike being used, has access to a soldering iron and basic electronics equipment and should be able to build out the system from home as needed. From there, the rest of the team can still adequately participate in schematic and PCB design, advising, and all necessary software components of the project.

This means that the project should be able to continue in sufficient capacity whether we are sent home or not and having already delivered the motor and bike to the machine shop, we are quickly approaching the pivotal milestone in our contingency plan.

3 Cost and Schedule

3.1 Cost

The average time we are spending on working for this project each per week will be approximately 8 hours. Considering an Electrical/Computer engineer's average hourly wage, we would estimate the cost to be **40$/hour x 2.5 x 8hours/week x 3engineers = 2,400$/week**

3.2 Schedule

The schedule for our project is as follows:

- Test our circuit on breadboards (Window: 10/1/2020 - 10/8/2020)
- Start working on mechanical part and installation with Machine Shop (Window: 09/292020 - 10/29/2020)
- Draw PCB (Window: 10/8/2020 - 10/15/2020)
- Write code and test it (Window: 10/15/2020 - 10/29/2020)

4 Safety and Ethics

We believe the main ethics concerns in our project stems from the responsible design and implementation of the mechanical components, which have the greatest potential for harm to the user.

To address this, we refer to IEEE 7.8 # 1. "to hold paramount the safety, health, and welfare of the public…" and 6. "...to undertake technological tasks for others only if qualified by training or experience…" which both guide our approach to the design. The way 7.8.1 applies is in the design itself.. By creating a system whose goal is to allow bicyclists to travel the road more safely, we are looking out for public interest. The implementation of guideline 7.8.6 will require that we consult others with more mechanical design experience to ensure that our design is both safe in principle, and practice as far as the user is concerned.

Additionally, there are environmental and health concerns associated with the use of a lead-acid battery, especially one deployed on a vehicle which will likely be stored outside. To ensure that the battery cannot cause harm to the user or environment, it will have to be properly enclosed such that weather and other external factors cannot effect it.

With regards to software, since we are relying for this experience to be powered completely by the user as well as information fed from the GPS module, one concern that arises is the lack of accurate measurements and statistics. Fortunately, the GPS receiver we had decided to use, the uBlox NEO-6M, is a 50-channel receiver [9]. While we need at most 12 channels in order to receive the most accurate measurement of one's location possible, a

50-channel receiver will ensure that we are able to pull location statistics based off of the 24 different GPS satellites in the sky right now.

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