A Proposal For An APRS Enabled Weather Station

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A proposal to create a weather station at NMT that can report data via radio

Tech Amateur Radio Association
New Mexico Tech
2021, November 11

Executive Summary

In this document, I am proposing to install a weather station on New Mexico Tech's (NMT) campus. This weather station will provide local measurements of temperature, pressure, humidity, rain, wind speed, and UV index. The station will run off a solar panel and battery so that it can function independent of an interrupted electrical service. The station will use a radio to automatically communicate its data to a preexisting infrastructure suited to this application. This network, called the Automatic Position/Packet Reporting/Repeating System (APRS), works well for my purpose since it is decentralized and as such, there is no reliance on any one node to make it out to the rest of the world. If we connected directly to NMT's network, we would be solely dependent on it not failing to operate. Finally, after proving the concept on campus, I would like to place another weather station on Socorro or Granite peak to compare the weather.

Abstract

In this document, I will be going over my proposal to put an APRS weather station on campus. It will be equipped with a combo temperature, pressure, and humidity sensor form Bosch. Wind speed will be measured with an anemometer and a rotary encoder. UV index will be approximated by a UV photodiode with a sensitivity centered around 310[nm] which is roughly the most harmful UV radiation. This will be a very crude approximation and it may be left out if its accuracy is seen to be too low in practice. Finally, a rain gauge will measure the amount of rainfall over a set time interval. The weather station will transmit its data via APRS (144.390[MHz] for North America) as a '-13' station so as not to rely on any one node to reach the internet. With this system in place, the data will be freely available to anyone over the internet and if that should go down, anyone would still be able to listen to the weather station itself, not relying on any external infrastructure. Solar power and battery storage will be used to further remove the reliance on external infrastructure. If the weather station can be proven here on campus, I would like to add another one on Socorro or Granite peak so that the weather can be compared between the two elevations.

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1 Introduction

I am proposing that an off grid weather station be built and installed on NMT's campus and if it works well, Socorro or Granite peak as well. The weather station will run off of a battery charged by a solar panel and have a radio capable of sending APRS transmissions so as not to reply on NMT's network for internet access. This project can roughly be broken down into four stages: prototyping, integration, installation and testing, and the mountain. For the first stage, each subsystem of the weather station will be tested individually to insure it works. The second stage will combine all the pieces and iron out any bugs that arise from integrating everything. For the third stage, the weather station will be installed somewhere suitably on campus and monitored to confirm proper operation and accuracy. Finally, for the fourth stage, permission will be sought, and hopefully granted, to place a second weather station at the top of 'M' mountain to compare the weather between the different elevations.

2 Motivation and Reasons

As you may or may not be aware of, Socorro is located in a bit of a radio dead zone; perfect for things like the Very Large Array (VLA) nearby, but terrible if you want to receive the weather information put out by the National Oceanic and Atmospheric Administration (NOAA). NOAA is the highest authority in the USA's meteorological infrastructure, and in fact, most weather services you are familiar with scrap their data from NOAA. So why is not being able to hear NOAA's weather broadcast such a big deal when you could simple look it up on the internet? Well that would require two external services, the internet and electric utility, to both be up and running. It is not hard to find examples of either or both failing, especially during inclement weather. Therefore, a local weather station, running off grid and freely broadcasting its data, should be considered as a highly beneficial public service.

There is another equally useful application for a local weather station. You may not have ever cared to notice or simply did not know anything was wrong, but no weather service that I have found, has ever reported the correct barometric pressure for Socorro. For example, at the time of writing, the barometric pressure in Socorro is being reported as 1.01 atmospheres. As Socorro is well above sea level (1.4[km] above), it should be clear that makes no sense. As measured by a BMP380 (a small form factor pressure sensor made by Bosch, a respectable name in the space), the real barometric pressure in Socorro is 0.853 atmospheres. For a possibly more relevant example, if you opened 5 different weather apps, you would get 5 different temperature values; I have seen differences of over 10° several times. The reasons for these inaccuracies are many but I believe the most relevant one is that very few if any actual measurements are made in Socorro, most of the data is inferred by a few base measurements of surrounding areas like albuquerque, historical data, and statistical models. As such, a weather station taking real, local measurements and reporting only true data should provide a nice boost to the accuracy of weather data in Socorro and allow for people to more accurately plan their day based on the weather.

3 Technical Overview

The weather station can be broken up into distinct modules and I will discuss them accordingly: central processor, APRS transceiver, sensors, data storage, power, and GPS. An overview of the entire weather station is provided at the end of this section in Figure 3.

3.1 Central Processor

An ESP32 module will be used for the main processor in the weather station. An ESP32 is more than powerful enough, and it has all the built in peripherals needed, to operate as the central processor with headroom to spare for future expandability. There is also the added benefit of built in WIFI so the weather station can be easily controlled remotely for testing and monitoring purposes. Although the ESP32 has a built in ’RTC’, it is not a true RTC and so an external one along with a backup coin cell will be added to keep accurate time.

3.2 APRS Transceiver

This system will consist of three parts: the antenna, a TNC, and the transceiver itself.

3.2.1 Antenna

For New Mexico, and most of North America actually, a frequency of 144.390[MHz] is used for APRS. As such, the antenna will be tuned for that exact frequency. To start with, a simple mag mount antenna will be used during testing and a wire dipole will later be constructed during the integration step as it will be much cheaper than using a store bought antenna while delivering comparable performance. An SMA connector will be used to connect the antenna feedline to the weather station because of its small size and signal integrity.

3.2.2 TNC

There are many designs out there for TNCs based on commonly available platforms such as Arduino. The TNC used in this weather station will be following the design of Piotr Wilkoń, a Polish ham radio operator [1]. Wilkoń’s design uses an STM32F103, which is significantly faster and more powerful than an Arduino, and allows his TNC design to be much more accurate and reliably than any others I have seen.

The TNC takes in serial data from some source, in this case the ESP32 acting as the central processor, and outputs it as an APRS packet encoded with AFSK and a PTT signal to some transceiver. The TNC is also responsibly for taking the incoming APRS packets, interpreting them, and sending them back to the ESP32.

3.2.3 Transceiver

The transceiver is what is responsible for taking the outbound audio data and transmitting it as radio waves as well as receiving radio waves and demodulating it into incoming audio. For the initial proof of concept, a cheap Baofeng HT will be used. Later, this will be swapped out for a standalone transceiver module like the ones sold by NiceRF.

The Baofeng will have to be configure manually when used for testing as it is designed to be used by a human and has no way to autonomously control it. The NiceRF module on the other hand is designed to be controlled by an embedded system so when it is substituted in, the ESP32 will take care of setting it up autonomously.

A note on these standalone RF modules: they frequently do not meet FCC requirements for spurious emissions [2] and as such, you must design in a high attenuation filter on the output in order to legally transmit radio waves. I have not yet measured a module from NiceRF yet myself though, so it could be that it does not need it. A passive Chebyshev ladder filter is easy enough to throw together that I plan to not bother measuring if it is required.

3.3 Sensors

The weather station will nominally be comprised of 6 sensors: A temperature, pressure, humidity, rain, wind speed, and UV sensor. The temperature, pressure, and humidity sensors will all be in one small package from a company called Bosch.

3.3.1 Bosch Combo Sensor

Bosch produces a full line of small form factor temperature, pressure, humidity, and gas sensors. For my purposes, I have chosen the BME280; a single module combining all three sensors which is very beneficial as it saves on space and supporting components. The combination sensor will run independently of the ESP32 and report its data via SPI or I2C whenever the ESP32 requests it. I have chosen to use SPI for the weather station based on its superior speed and the ESP32's available peripherals.

3.3.2 Rain Gauge

For an automated measurement of rain fall, there is really only one way to do it: the tipping bucket. While other, more exciting methods exist such as optical (using lasers to count raindrops) or acoustic (estimating rainfall by how loud it is), the tipping bucket is by far the most common and simple in function. A tipping bucket rain gauge, as the name implies, consists of a bucket that will tip over when a certain amount of water fills it. By counting the number of times the bucket tips over a time interval and multiplying that by the amount of water it takes to tip it, a reasonably good estimate of the total rainfall can be achieved. To count the number of times the bucket tips, a reed switch is placed under the bucket in such a way that a magnet on the bucket will trigger it every time the bucket tips. The signal from this will be a bit bouncy so it is run through a RC network to slow it down and clean it up in the process; the time constant of the RC network is not critical, something like 10[ms] will work, but fine tune the value to the situation. Then the signal is sent through a Schmitt trigger to produce the final clean pulse. The full debouncing circuit can be seen in Figure 1. Finally, the clean signal ends up at the ESP32's pulse counter input pin.

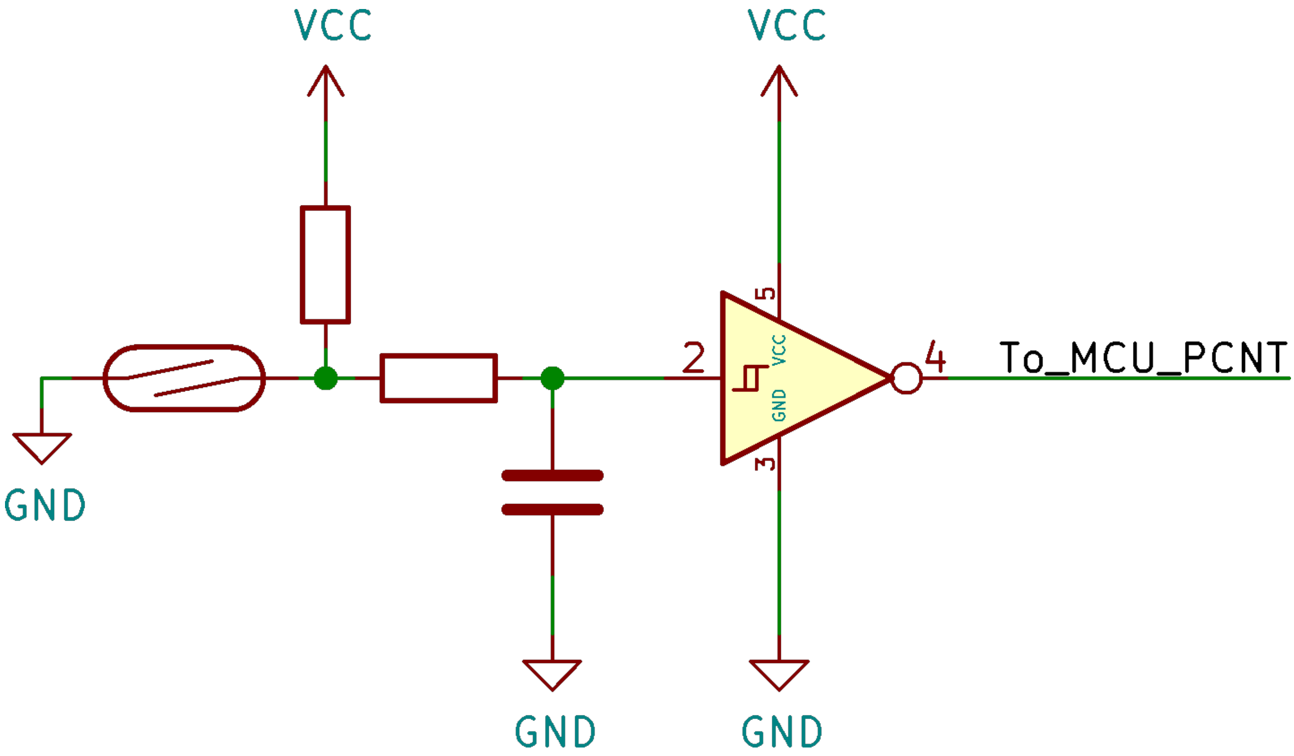

Figure 1: A hardware debouncing circuit

An Interesting Aside There could be a potential problem with this method of detecting the bucket tipping: the reed switch may be sensitive to RF. The first method used to detect RF was a small device very similar to a reed switch in function; it worked by physically clamping shut in the presence of strong enough RF. Whether or not I will have to worry about that given the relatively low transmit power and since I am using a modern reed switch, that accidental behavior may have already been designed out, only testing can determine.

3.3.3 Wind Speed

Wind speed is measured with an instrument called an anemometer. The angular speed of the anemometer is proportional to the wind speed and as such, can be calculated easily once you have an equation. To measure the angular speed of the anemometer, there are two simple ways I considered for this weather station: a rotary encoder, and a Hall Effect sensor. I decided to use the rotary encoder over the Hall Effect sensor for two reasons. First, the rotary encoder method will add less mass to the anemometer shaft and therefore minimize inertia. And second, the rotary encoder will produce pulses instead of the Hall Effect sensor's cosine wave. This will be less computationally intensive to interpret.

In order to find the angular velocity of the anemometer, the pulses from the rotary encoder will be feed into a counter peripheral of the ESP32. Then, after a set time interval of say one minute, the number of counts can be converted to a number of revolutions per unit time. This is by definition the angular velocity of the rotary encoder, which is the same as the angular velocity of the anemometer. This angular velocity is then used to calculate the wind speed.

3.3.4 UV Sensor

The purpose of this UV sensor is to approximate the UV index. I say approximate because the UV index is a very complex figure that takes in many factors to produce the familiar 1 through 11+ scale [3]. For the level of complexity and cost of this weather station, there is no way to measure and calculate even the simplest model for UV index as that requires a measurement of the intensity of UV radiation at all frequencies from 200[nm] to 400[nm]. The best I can do for this weather station is a UV photodiode that can be fed into a transimpedance amplifier, Figure 2, to produce a voltage proportional to the amount of UV radiation that hits it. The reason the signal coming out of a photodiode can not be used to gain any true UV intensity data is because what comes out of the photodiode is a jumbled, nonlinear "average" of a wide chunk of the UV spectrum. As such, the signal out of the photodiode can only be roughly mapped to a UV index value and not used to calculate the value directly. If the accuracy of this photodiode method of estimating the UV index is too low, it will be left off entirely for the final weather station.

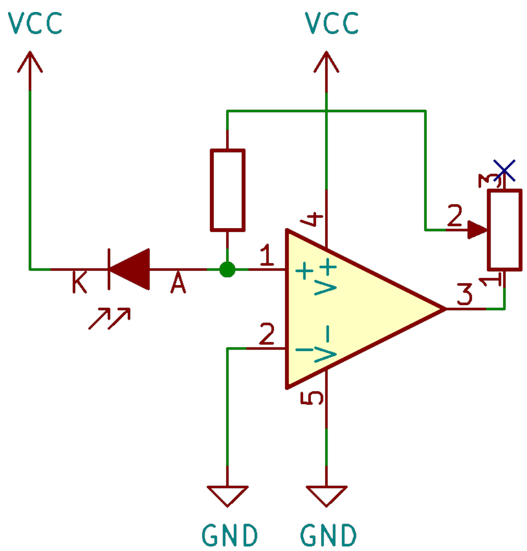

Figure 2: A UV photodiode connected to a transimpedance amplifier with variable gain

3.4 Data Storage

A micro SD card will be attached to the ESP32 to store all the timestamped data that is produced. So as not to produce excessive load and radio traffic, the weather station will only report its data once every 10 minutes as an average for the last 10 minutes. In the mean time between transmissions, the weather station will need somewhere to store its data. Micro SD cards are extremely dense and are well supported because of their age and ubiquity. The ESP32 even has a dedicated peripheral to communicate with SD cards.

3.5 Power

As an embedded system, this weather station will not consume much power. Even when transmitting, by far the most energy intensive part, very little power is required, on the order of 1 or 2 watts max. By contrast, modern phones can take multiply tens of watts when they charge. As such, even a small solar panel should be plenty to sustain this weather station indefinitely. Of course, a suitably sized battery must also be present to power the weather station during the night. Quick napkin math suggests that 30[WHr] will be the largest needed battery for a worst case energy consumption. That 30[WHr] figure is very easy to exceed in a small size with the battery technologies available today.

3.6 GPS

GPS is not strictly necessary as the location of the weather station and time can be manually loaded at the beginning. With that being said, including a GPS module in the weather station adds very little cost and complexity while offering a few benefits:

1. If the weather station can get its own location automatically, than it can be moved without any hassle of reprogramming the coordinates. This will make the weather station more versatile, granted the times a weather station needs to be moved significant distances are rare.

2. While an RTC can be reasonably accurate over a long period of time, GPS time is considered the golden standard for wirelessly syncing clocks. GPS is also significantly easier to sync to than the previous standard of WWV.

The reason why location is important to the weather station is that APRS nodes usually broadcast their location along with their data [4]. I have even seen some APRS Clients that do not work without providing a location.

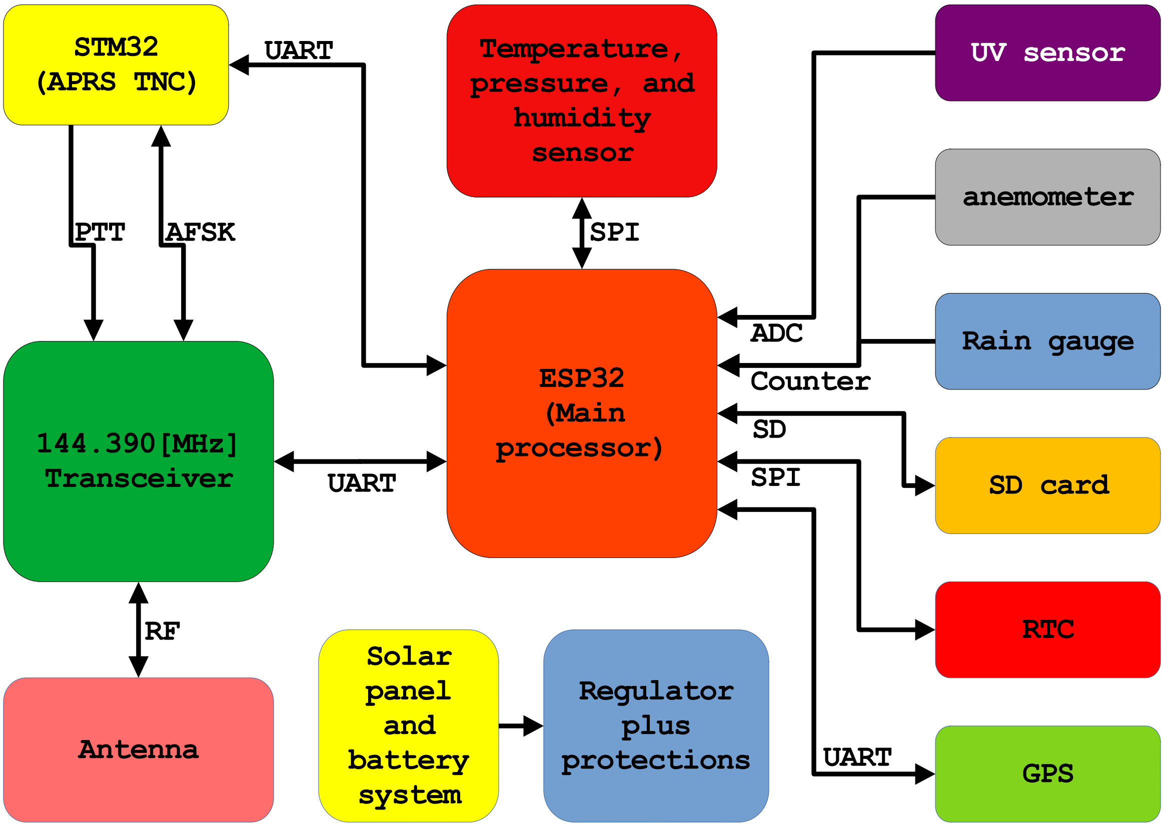

Figure 3: An overview of the topology of the weather station

4 Qualifications

I am a junior level electrical engineer at NMT as well as an Extra class radio operator. As my main focus as an electrical engineer is embedded systems, a weather station consisting of many sensors, microcontrollers, and the hardware to enabled radio communications is right up my alley. I am taking on this project as the President of the Tech Amateur Radio Association (TARA).

5 Budget

It is impossible at this time to provide an exact budget and cost breakdown. This is for several reasons, the main two being:

1. The world is currently in the middle of a global electronics shortage and as such, prices and stock of components varies wildly day to day.

2. A non-insignificant amount of this weather station will be designed from the ground up so there is not any price tag to look at before hand.

With that being said, a second order approximation for the cost of a weather station like this is around 250$. Below is a table, Figure 4, containing the prices used to come up with the 250$ estimation.

Item	Price [$]
ESP32 Module	10.50
STM32 Dev Board	11.00
NiceRF Module	16.30
Mag Mount 2m Antenna	25.00
GPS Module	10.00
BME280	4.00
UV Sensor	<1.00
Rain Gauge	15.00
Anemometer	15.00
RTC	5.00
SC Card	2.00
Solar Panel battery pack	50.00
Buck Regulator	5.00
Electrical Components	10.00
Final PCB Manufacturing	20.00
Housing	20.00
Total	219.80

Figure 4: The projected budget for the weather station

6 Schedule

Because of the structure of this year, the only available day to work on this weather station is every Saturday and every other Friday when we hold our TARA meetings. The breakdown of time for the four stages are as follows:

1. Prototyping: 4 weeks
2. Integration: 6 weeks
3. Installation and Testing: Only one day is needed to install the weather station somewhere. As for testing, a month or two of hands free operation should be enough, though obviously one full weather cycle would be better.
4. The Mountain: As with the initial installation, only one day will be required for the actual installation. The time sink will come from submitting the request and waiting for that to go through bureaucratic approval.

If these times seem long, keep in mind that only 3 days of every two weeks are available as actual working days.

7 Conclusion

Everyone relies on accurate weather data and forecasts to plan their day and attire. If you see that it will be freezing rain tomorrow, you would not plan a picnic. If you see that it is 38° outside with a UV index of 10, you will dress appropriately and wear sunscreen. Given Socorro's small size and relative isolation, few if any weather services take actual measurements in it, resulting in less accurate and sometimes down right incorrect weather data and forecasts. I am proposing a relatively cheap and robust weather station to be built and placed in Socorro to aid in gaining more accurate weather conditions and predictions. The data will be freely available to anyone who wants it while relying on the minimum amount of infrastructure. The weather station will of course be open source so that anyone who wants to can freely and easily copy it, thereby allowing the greatest number of people to benefit from it.

Glossary

AFSK Audio Frequency Shift Keying, a system of encoding data were one audibly tone represents a zero and another represents a one.

Anemometer A instrument that measures wind speed based on how it affects an object.

APRS Automatic Position/Packet Reporting/Repeating System, a system made to disseminate defined packets across a network.

Chebyshev Filter A type of filter with a steep rolloff and ripple in either the passband or stopband.

Extra Class Radio Operator The highest class of amateur radio license given in the USA.

FCC Federal Communication Commission, the agency in charge of everything wireless in the USA.

Feedline The cable that takes your signal from the transceiver to the antenna, usually coax.

Hall Effect The generation of a voltage in a conductor orthogonal to both an applied current and magnetic field.

HT Handheld Transceiver, informally called Handy Talky or walkie talkie.

NOAA National Oceanic and Atmospheric Administration

Photodiode A diode that allows current to flow in the reverse direction proportional to the intensity of the light hitting it.

PTT Push To Talk

Rotary Encoder An electromechanical device that converts an angular position to an analog or digital signal of some kind.

RTC Real Time Clock

SMA SubMiniature version A, a coax connector with a 50[Ω] impedance usable at higher frequencies.

TNC Terminal Node Controller, a device used primarily by amateur radio operator to send digital packets over analog RF.

UV Index UltraViolet index, a 0 to 11+ scale that conveys the level of danger posed by UV radiation outside at a given time and place.

WWV A radio station in Fort Collins, Colorado that continuously broadcasts the time.

References

[1] P. Wilkoń. "Vp-digi: Cheap and functional open-source aprs digipeater controller with kiss modem." (Sep. 2021), [Online]. Available: https://sq8l.pzk.pl/index.php/vp-digi-cheap-and-functional-aprs-digipeater-controller-with-kiss-modem/.

[2] Emission standards for the Amateru Radio Service, 47 C.F.R § 97.307. (2021).

[3] EPA. "Calculating the uv index." (Nov. 2021), [Online]. Available: https://www.epa.gov/sunsafety/calculating-uv-index-0.

[4] The APRS Working Group. "Automatic position reporting system." (Aug. 2000), [Online]. Available: http://www.aprs.org/doc/APRS101.PDF.