An Improved Protocol for Precipitation Measurement

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Research Overview

Objective: Develop an alternative protocol for measuring weather precipitation that takes into account impact force, size of element and duration of event.

- ❖ Impact force was measured via voltage, which is directly proportional, measured with a mounted piezoelectric component.
- ❖ Droplet size at the moment of impact was recorded with a flour covered baking tray
- ❖ RPU formula was applied to the weather event based on the average values of the precipitation elements
- ❖ Altogether, the **low equipment cost and simple formula allow for a greatly improved protocol** for precipitation measurement.

Background

Meteorology is the defined as the "scientific study of the atmosphere"

- **2001** – National Weather Service begins to produce a Unified Surface Analysis, ending duplication of effort.
- **2003** – NOAA hurricane experts issue first experimental Eastern Pacific Hurricane Outlook.
- **2006** - Weather radar improved by adding common precipitation to it such as freezing rain, rain and snow mixed, and snow for the first time.
- **2007** – The Fujita scale is replaced with the Enhanced Fujita Scale for National Weather Service tornado assessments.
- **2010s** - Weather radar gains smaller, more detailed options.

Despite changes in approaches, there have been **no significant advances** in accurately determining measurements of weather events.

Precipitation Measurement

Accumulation

- ❖ How much precipitation has occurred
- ❖ Inches/cm or sometimes in/hr
- ❖ Common in weather forecasts

Precipitation element size

- ❖ Pioneered by NASA's Global Precipitation Measurement Core Observatory
- ❖ Measured by satellites in orbit via microwave reflection
- ❖ Scientific analysis tool

Problem: Currently there is **no method** to describe the amount of energy during a precipitation event.

Solution: Intensity of Rainfall Measured Through New Unit

New unit to describe the amount of precipitation energy (Rain Power Unit)

$$RPU\ value = \frac{\frac{|Voltage\ (volts)|}{Area\ (mm^2)}}{Time\ (seconds)}$$

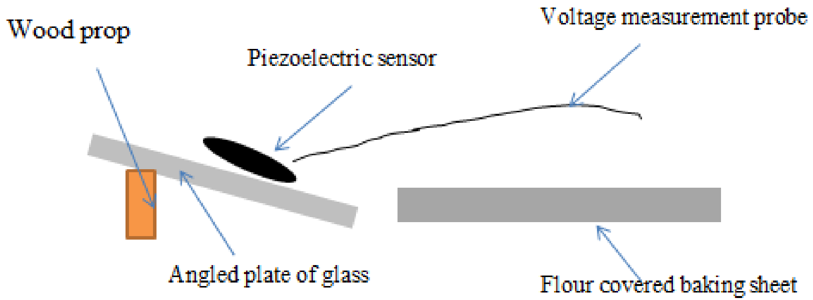
Measures the impact force on a given area over a certain duration.

Solution takes into account impact velocity, precipitation element size and duration of weather event.

Methodology

Impact force measured with a piezoelectric sensor (voltage produced with deformation)

Precipitation element size @ moment of impact was measured with a flour covered baking sheet



Recorded Area at Moment of Impact

Voltage Measurement Setup

Reasoning

Piezoelectric component- produces voltage upon deformation (impact)

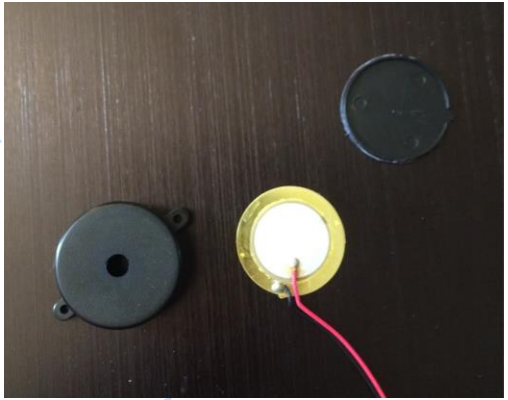
- ~$3 compared to $200+ force plate
- Readily available

Flour- records size of precipitation element at moment of impact

- Very inexpensive
- Readily available

Most expensive component would be voltage sensor ($11)

Flour impact capture



Piezoelectric component

Raw Data

5 data points per second (18000/hr)

Voltage probe recorded time (s) and voltage (volts)

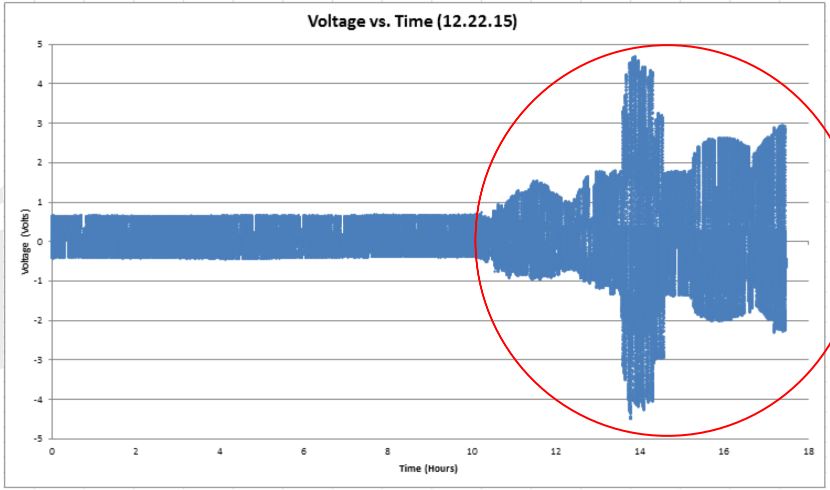
Sample Data Table 1: Time and Voltage Data (12.31.15)

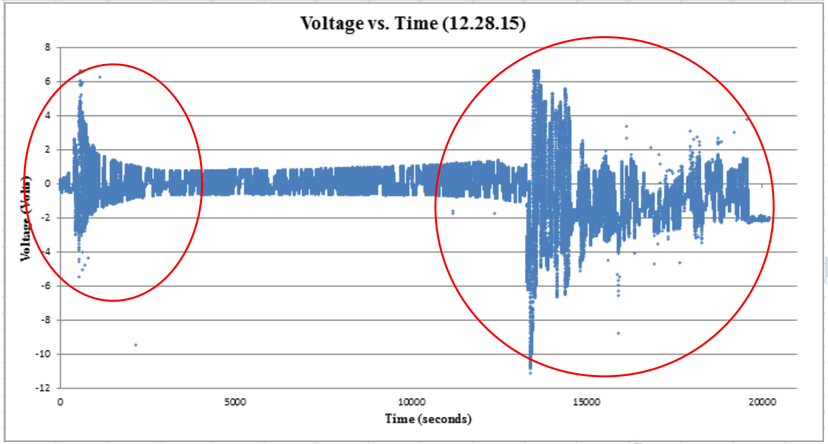
Tine (seconds)	Voltage (volts)
0.0	0.008
0.2	0.008
40339.2	-0.149

Axes of the precipitation element was measured in mm, then the area was calculated

Sample Data Table 2: Area of Precipitation Elements at Moment of Impact (12.31.15)

Axis 1 (mm)	Axis 2 (mm)	Area (mm^2)
3	1	9.4248
3	4	37.6991
4	3	37.6991



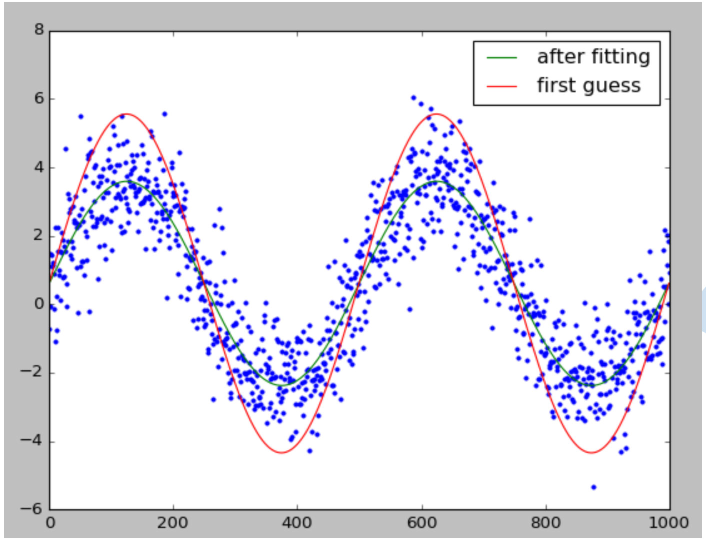


Data Analysis

Piezoelectric component has background noise.

- ❖ Developed a Python program which was applied to the background noise to produce a sinusoidal regression
- ❖ Regression was applied to main data in order to remove background noise
- ❖ Offline post-hoc analysis due to the large volume of data (~400 000 per data set)

```python
import numpy as np
from scipy.optimize import leastsq
import pylab as plt

N = 1000 # number of data points
t = np.linspace(0, 4*np.pi, N)
data = 3.0*np.sin(t+0.001) + 0.5 + np.random.randn(N) # create artificial data with noise

guess_mean = np.mean(data)
guess_std = 3*np.std(data)/(2**0.5)
guess_phase = 0

#plot first estimate
data_first_guess = guess_std*np.sin(t+guess_phase) + guess_mean

#Define the function to optimize- minimize the difference
#between the actual data and "guessed" parameters
optimize_func = lambda x: x[0]*np.sin(t+x[1]) + x[2] - data
est_std, est_phase, est_mean = leastsq(optimize_func, [guess_std, guess_phase, guess_mean])[0]

# recreate the fitted curve using the optimized parameters
data_fit = est_std*np.sin(t+est_phase) + est_mean

plt.plot(data, '.')
plt.plot(data_fit, label='after fitting')
plt.plot(data_first_guess, label='first guess')
plt.legend()
plt.show()
```

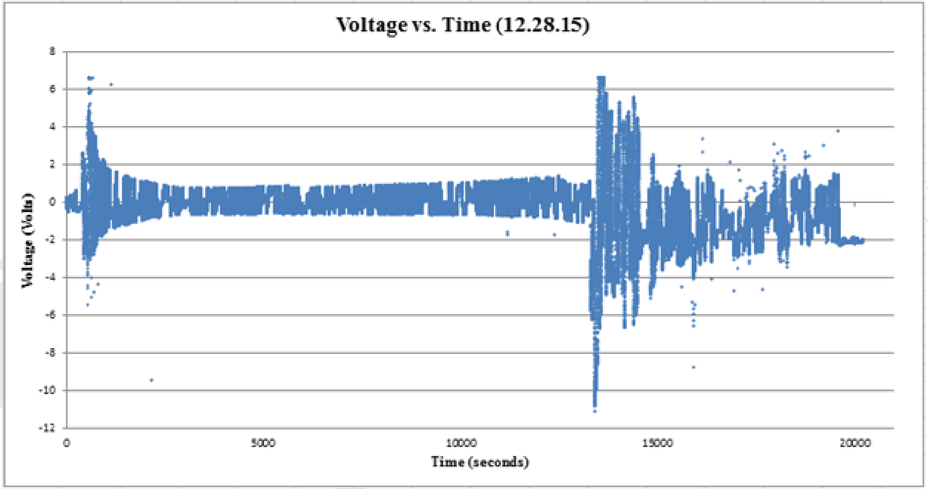


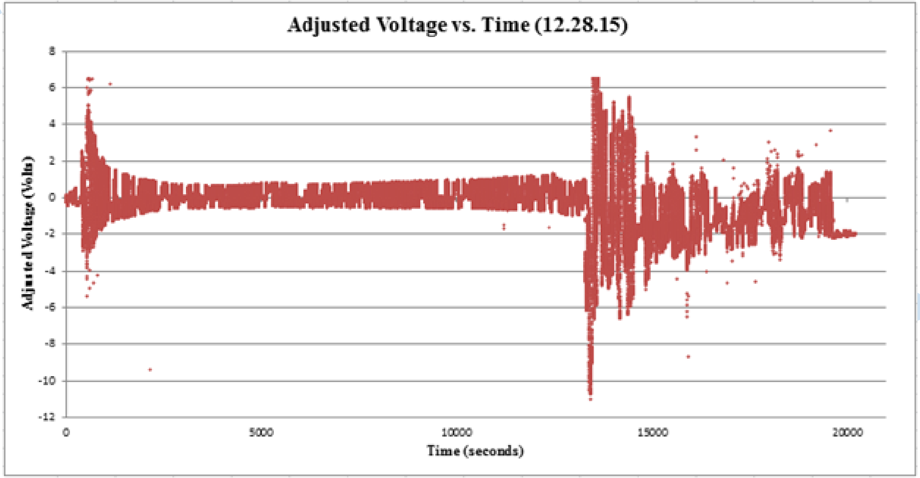
Data Analysis

- ❖ Due to large volume of data (~400 000 points per data set), an Excel logic function was used.

```
if voltage<0:
    voltage=voltage+average_voltage

elif voltage>0:
    voltage=voltage-average_voltage

else:
    pass
```

- ❖ Using the average voltage from the background noise, the actual data could be smoothed.
- ❖ Sub-optimal since it places it closer to the average instead of removing the noise.





Typical Results After Data Analysis

Table 3: Summative Total Precipitation Data (12.23.15-12.31.15)

Precipitation Event	Duration (Minutes)	Avg. RPU	Max RPU
12.23.15-1	60.367	0.44611	31.58201
12.23.15-2	136.567	2.03058	83.71443
12.23.15-3	28.917	0.14789	6.35767
12.28.15-1	43.333	0.04244	74.59335
12.28.15-2	109.783	20.37843	222.36286
12.29.15	64.277	32.22442	119.72495
12.30.15	36.717	120.04954	358.05810
12.31.15	363.047	4.08646	798.74593

- ❖ Data shows that overall RPU values are not directly tied to duration of the precipitation event, as intended by the RPU formula.
- ❖ 12.31.15 event; long event can have a low average RPU value, but a high max RPU value (signifying a heavy rain at some point within the event).
- ❖ 12.30.15 event; shows that a short and intense event produces very high RPU values.

Table 4: Summative Precipitation Data per Second (12.23.15-12.31.15)

Precipitation Event	Duration (Minutes)	Avg. RPU/Sec	Max RPU/Sec
12.23.15-1	60.367	3.40054E-08	2.78248E-06
12.23.15-2	136.567	3.02432E-08	1.24683E-06
12.23.15-3	28.917	4.91276E-08	2.11203E-06
12.28.15-1	43.333	6.27843E-09	1.10345E-05
12.28.15-2	109.783	4.69673E-07	5.12492E-06
12.29.15	64.277	2.16659E-06	8.04962E-06
12.30.15	36.717	2.47361E-05	7.3321E-05
12.31.15	363.047	8.61231E-09	1.68338E-06

- ❖ RPU values per second, essentially the combined RPU value of five data points.
- ❖ 12.30.15 event; high RPU per second, signifying a large quantity of precipitation elements in one second.
- ❖ Within that event, there was a high max RPU per second, meaning that the elements had a high impact force per unit area.

Results and Conclusions

- ❖ The improved protocol for precipitation measurement exceeded the original objective.
- ❖ The RPU formula allows for more aspects of the precipitation event to be recorded and it also accounts for the interaction between them. Consequently, this protocol for measurement is far superior to the current size and accumulation methods.
- ❖ The ideal approach would be to employ all three methods (size, accumulation, RPU) which produces the most descriptive analyses.
- ❖ The new RPU precipitation protocol is superior to current precipitation methods, but does not supplant them.

RPU Applications

- **Engineering-** A RPU value is essentially a measure of the energy of the precipitation element/event, so engineers can adjust their projects according to the required RPU strain. Currently, projects are often based on accumulation values, which are not a reliable measure of stress. With the implementation of this protocol, engineering safety practices could change drastically.
- **Weather Analysis-** Having a better method of precipitation measurement will allow climate scientists to better categorize and analyze weather events. Ergo, the scientists will have a more complete model/record of any events they wish to study.
- **Weather Prediction-** If meteorologists can provide an RPU estimate for the weather event, people can prepare accordingly since RPU provides information about the weather event's duration, intensity, and precipitation elements, all in all leading to more descriptive predictions.

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