Measurement of Wind Direction

Wind is a key environmental factor at the AIGO site, potentially affecting both seismic noise and particle contamination levels. The environmental data acquisition system is equipped to record both wind speed and wind direction. Wind speed is recorded as an analog voltage proportional to the count rate produced by a once-per-turn reed switch on the anemometer cup wheel. Wind direction is likewise recorded as an analog voltage between 0 and +5 Vdc, but is produced by a potentiometer connected to the wind vane and configured as a voltage divider. The potentiometer does not have internal stops, and may rotate continuously through 360° any number of times.

This monograph describes the data conditioning necessary to produce sensible wind direction data.

1. The Problem With Wrapping Values

The wind direction sensor produces a linear, continuous signal between 0 and +5 Vdc with slew rates normally on the order of a few volts per second. Zero volts represents due north, 2.5 V represents south, and 5 V represents north again, after a complete vane rotation. This situation is referred to as a “wrapping value.”

The problem occurs at the discontinuous transition from east of north to just west of north, as the signal voltage changes abruptly from 5 V to 0V. We intuitively interpret these two extremes as one and the same physical direction. Numerically, however, this transition creates problems and possible serious errors.

Consider the simulated example in Fig. 1, in which the wind direction changes gradually from NE to NW. Due to turbulence, there are also random variations in instantaneous wind direction. When the wind direction is close to due north, the signal may be either 0 or +5, and will fluctuate randomly between these two values. The data acquisition system will occasionally sample the signal during such a transition. The result is that when the direction is due north, the recorded signal may be any value between 0 and +5, with the “expectation” value being 2.5 Vdc, which represents “South,” the exact opposite of the correct direction.

If the data are intentionally time-averaged, the steady-state result for a northerly wind will always be 2.5 Vdc, or “South.” That is, a 100% error is 100% assured every single time.

2. Solutions

It is possible to program the data acquisition computer with heuristic rules which convert the voltage signal into wind directions. Such rules are not an ideal solution, because they are prone to errors, apply to only a limited range of conditions, can introduce artefacts into the data, and are not easily maintained into the future.

Another solution is to immediately convert the signal values to angle measurement units (radians or degrees). But this does not address the problem of subsequent filtering resulting in erroneous values. Further, one could convert the angle corresponding to each data point into a complex number on the unit circle. This removes the ambiguity, but requires twice the storage space for data, and requires either significant real-time processing power (with trig functions), or a post-processing stage. In either case, there remains the possibility of errors due to sampling the signal during a 0 to 5 Vdc transition.

A method derived from the techniques of Fuzzy Logic is presented here which solves this problem in a reliable and rigorous way. The technique produces a sufficiently simple algorithm that real-time processing is a possibility. Furthermore, the resulting data set is efficient and easily displayed, interpreted, and (most importantly) statistically analyzed.
Fuzzy logic is concerned with finding rigorous ways of making accurate decisions based on numerical data (in this case, the correct categorization of data.) It is most useful when the data appear to be indeterminate, or have only subtle correlations to the correct decision or classification. In spite of its name, Fuzzy Logic is very accurate, and is mathematically precise. It is, in fact, the data that are fuzzy, not the logic.

3. A Simple Categorization Algorithm

It is assumed that no greater resolution of wind direction is required than the eight basic directions: N, NW, W, SW, S, SE, E, NE. Each voltage reading acquired from the wind direction sensor is compared to eight reference values, and the sample is assigned to one of eight histogram-style bins (see Table 1). A count is added to the total of that bin, and the sampled value is then discarded. In general, these bins would be basis functions having many possible shapes, and which often overlap. The simplest case, and sufficient for present purposes, are the flat, non-overlapping basis functions represented by histogram bins.

After a certain number of data points have been binned, another comparison is performed to determine the bin with the largest count. This bin represents the true average wind direction at the time of the middle data sample. The bin sums are now all cleared, and the counting resumes.

The number of points to sample between checking for a maximum (called the re-sampling period) depends on the required temporal resolution in wind direction. As mentioned before, turbulence
creates many random fluctuations in direction, making the instantaneous, single-point wind direction a meaningless quantity. Meaningful wind direction data should represent at least several seconds’ worth of data. Simulations presented here used a 25-sample re-sampling period.

Table 1. Wind Direction Range Definitions.

<table>
<thead>
<tr>
<th>Wind Direction</th>
<th>Voltage Range</th>
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<tbody>
<tr>
<td>N</td>
<td>V &lt; 0.31; V &gt;= 4.69</td>
</tr>
<tr>
<td>NW</td>
<td>0.31 &lt;= V &lt; 0.94</td>
</tr>
<tr>
<td>W</td>
<td>0.94 &lt;= V &lt; 1.56</td>
</tr>
<tr>
<td>SW</td>
<td>1.56 &lt;= V &lt; 2.19</td>
</tr>
<tr>
<td>S</td>
<td>2.19 &lt;= V &lt; 2.81</td>
</tr>
<tr>
<td>SE</td>
<td>2.81 &lt;= V &lt; 3.44</td>
</tr>
<tr>
<td>E</td>
<td>3.44 &lt;= V &lt; 4.06</td>
</tr>
<tr>
<td>NE</td>
<td>4.06 &lt;= V &lt; 4.64</td>
</tr>
</tbody>
</table>

Re-sampling and maximizing has the effect of eliminating any spurious false readings of data traversing the “North” discontinuity. It also has the effect of exactly averaging the wind directions over the re-sampling period, as a free bonus. The total number of operations required is quite small. For each sample, there are a maximum of eight real value comparisons, and one integer addition.

Figure 2. Histogram of a 25-sample re-sampling period. Although an occasional single data point is misread due to the constant transitions between 0 and 5 V, the majority are distinctly one or the other, classifying this resample period as clearly “north.”

Consider again the simulated data in Fig. 1. A typical re-sampling period during the “North” transition results in the bin histogram shown in Fig. 2. Obviously, the prevailing wind direction is north, with only a few spurious data points resulting from sampling across the discontinuity. Fig. 3 shows the same data after the complete Fuzzy-Logic reprocessing.
Figure 3. Results of Fuzzy-Logic processing. Each 25-sample re-sampling period is displayed as a green circle. Data samples classified as “north” are displayed as +5 Vdc for comparison on the graph. The Fuzzy-Logic algorithm was error-free, even while the time-average result showed incorrect results due to numerous 0 to 5 Vdc transitions.

Processing wind direction data in this way produces unambiguous, error-free results. What is especially important, wind direction data is now in a categorical format, which is particularly useful in statistical analysis, such as correlations with other data sets.

It is estimated that every few hundred thousand re-sampling periods that should have a due north result could be miscategorized. That is, if we are extremely unlucky and happen to sample the signal right in the middle of a 0-5 Vdc transition more than half of any 25 consecutive samples, then some category bin other than “North” could have the highest count for that period. Even this pessimistic estimate is incomparable to the 100% guaranteed error that results from time-averaging the signal.

Conclusions

It is important for anyone involved with data analysis to be extremely careful when dealing with wind direction data. Standard signal processing techniques fail spectacularly when applied to this type of data set. A Fuzzy Logic reprocessing step is recommended.

A real-time processing stage which categorizes the incoming data is also very feasible. The number of operations required to implement it is very small. This would have the important benefit that anyone looking at wind direction data in the future would find simple, categorical data, and would not be blindsided by the “wrapping value” pitfall.