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NEURAL NETWORKS AS A SOLUTION TO SPONTANEOUS EMISSION IN THE ICECUBE NEUTRINO DETECTOR

Le Nguyen
Department of Physics & Astronomy, Michigan State University, East Lansing, MI

Abstract

Neutrinos are a group of fundamental particles that are of interest to high energy physicists and astrophysicists. The IceCube detector is designed to pick up the radiation signature of neutrinos with an array of Digital Optical Modules. These modules have a fundamental, physical, flaw in their main component that spontaneously emits light. The spontaneous emissions of light lead to false reports of neutrino events. Since the flaw is inherent to the device, a computational solution is needed to identify and mask out false data. Neural networks (and other machine learning techniques) have been shown to be effective at data classification and can be used to solve the IceCube detector's spontaneous emission problem.

1. BACKGROUND

The IceCube detector is located at the Amundsen-Scott South Pole Station, Antarctica. Buried under the Antartica surface, extending to a depth of 2,500 meters are eighty-six cables spaced out over a cubic kilometer of ice; each of these cables holds sixty Digital Optical Modules (DOMS). These cables, and the DOMS they contain create the largest neutrino detector the world has ever seen (Figure 1).

The gigaton of ice the strings of DOMs are embedded in is required to detect neutrinos. Since neutrinos are the smallest of the fundamental particles, and are uncharged, they hardly interact with matter. The sheer quantity of ice makes a measurable amount of neutrinos interactions possible. By chance, neutrinos will interact with nucleons in the detector's ice, which will create Cherenkov radiation, radiation that travels faster than light inside of a medium, that will propagate through ice and get detected by an array of DOMS. (2)

Neutrinos are of interest to high energy physicists, and astrophysicists alike. Their low interaction rate means they can travel across the universe completely unchanged. The unchanged characteristics of neutrinos can lead to key insights on the object or event that created them. Notable examples include the recent discovery of a known blazar being a high energy neutrino source, and sterile neutrinos being proposed as a dark matter candidate. With these and other discoveries, IceCube continues to expand the field of neutrino astronomy.

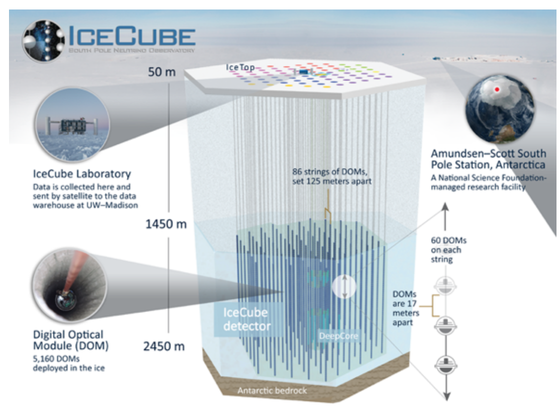

Figure 1. A depiction of the IceCube detector (1).

2. INSTRUMENTS

Digital Optical Modules (DOMS) are a 10-inch diameter Photo Multiplier Tube (PMT) incase in a 0.5-inch thick glass sphere with various other calibration and communication components (2). The PMT is the heart of the device. It is the component that picks up the resulting radiation from a neutrino interact.

A PMT works by using the photoelectric effect and a series of dynodes. An incoming photon hits an initial photocathode on the PMT which knocks loose an electron. The electron is then sent to hit a dynode, which then knocks loose more electrons directed to hit more dynodes. Each dynode adds an exponential number of electrons and the multiplicative effect creates a detectable current picked up by an anode (3, and see Figure 2). In this way, a single photon can be amplified to detectable signature.

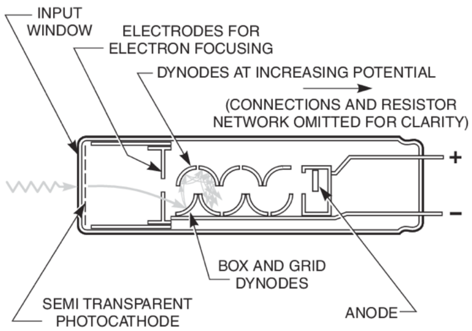

Figure 2. Schematic of a photomultiplier tube (4)

3. PROBLEM

The PMTs amplify the signature of a single photon to an order that is detectable. This detectable current is about 70 mA from a single photon. In order to do this, the voltage between the dynodes and the anode needs to be high, around 1500V (2). This creates the problem of spontaneous emission. Inside of a PMT is a near, but not perfect vacuum. The unwanted particles between such a high voltage in a PMT can carry a current, which will create a spark. This spark generates light inside of the PMT that will trigger the dynode electron cascade and is picked up by the PMT itself which will report a neutrino detection. Spontaneous emission can also be created by thermal effects inside of the PMT:

"It is caused by the thermionic emission of electrons from the surface of the detector hardware. When the free electrons in a metal surface gain enough kinetic energy to overcome the metal's work function, a thermionic current can be created. The emission of electrons from a metal surface is a Poisson process that strongly depends on the temperature of the metal."(5)

Though the thermionic emission is less prevalent because of the temperature the DOMs are at in the Antarctic ice, it is still an error factor.

The problem is exacerbated by the light generated inside of the PMT of one DOM propagating through the ice and being detected by other PMTS in other DOMs. This makes spontaneous emissions further look like neutrino interactions, since they are picked up by multiple detectors. This problem is prevalent enough in the IceCube detector that the team calls it "dark noise", since it is detected in absence of a neutrino interactions' Cherenkov radiation, and has to be accounted for when looking at a possible neutrino event.

4. SOLUTION

The IceCube team has already taken measures to reduce the effects of dark noise. These include making the PMTs out of custom low radioactivity glass, which minimized the probability of spontaneous emission trigger by particles decaying off the PMTs' exterior. Also, dark vinyl tape on the DOMs, "The taping is observed to reduce the low-temperature noise rate by about half. The reduction is attributed to absorption of outward going decay photons, which can otherwise be channeled to the photocathode via internal reflection." (2).

These measures reduce the effects of dark noise, but do not nullify it. Unfortunately, it is impossible to pull a perfect vacuum on Earth, and it is impossible to get rid of thermal background effects. Nothing can be done to fully extinguish spontaneous emission or change the fact a PMT cannot distinguish between the photon from a neutrino event and unintended background noise. A computational solution is necessary for this problem, not a physical one.

The DOMs are unable to distinguish between dark noise and real neutrino events, so a method is needed to filter out spontaneous emission readings from neutrino event readings. A promising path to solving this problem lies in creating a neural network to analyze spontaneous emission events. A neural network "consists of large number of units (neurons) joined together in a pattern of connections" (6). It takes in a set of inputs and outputs and establishes a pattern between them. This can be used to look at outputted data from DOMs and determine if it is an actual neutrino event or spontaneous emission.

This would be done by creating two sets of data. DOM outputs from multiple neutrino events, and DOM outputs from multiple spontaneous emissions. The neural network would take in the set of outputs for the actual neutrino events and be told that said readings corresponded to an actual neutrino event. The neural network would then establish a set of characteristic patterns between the set of outputs and use it to identify if a new set fits the pattern; thus, identifying if it is an actual neutrino event. The same process would be done for spontaneous emissions, giving the neural network the ability to distinguish between the two.

The problem of classification has been thoroughly explored with neural networks and other machine learning techniques. "Machine learning techniques are applicable in numerous domains... from: pattern recognition, image recognition, medical diagnosis, commodity trading, music composition, computer games and various control applications" (6). Any application where a pattern can be established between a set of data and an outcome. Which makes a machine learning approach an optimal solution to the spontaneous emission problem.

As an example, a dead ringer for spontaneous emissions is that the origin of the light is from inside of a DOM. A neural network, given enough data, would establish this pattern. Spontaneous emission events have the origin of light propagation inside of a DOM. If the neural network was given a set of data where this was true, say one DOM reports a reading and then all the DOMs around it report a reading at the same time (light propagated out of one DOM spherically and activated its neighboring DOMs simultaneously), it would determine that set of outputs correspond to a spontaneous emission event, because the data was similar to the outputs of all spontaneous emission events it has seen. In actual application, the characterizing neural network would look at more relevant features, but all in all would work in the same way.

5. CONCLUSION

The IceCube neutrino detector's array of DOMs, have a fundamental flaw. The central neutrino radiation detecting component, the PMT, can spontaneously emit light that will trigger itself and detectors around it; leading to reports of false neutrino events. This problem is physically inherent to the device and is unavoidable. A computational method to identify and filter out the false event data is necessary. The use of machine learning techniques, especially neural networks, have been shown to be optimal at solving data classification problems. Use of a neural network to classify DOM output data would eliminate the inherit error of spontaneous emission.

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