Generating "Truly Random" Digits Using Quantum Optics with Laser Manipulation

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Abstract

The definition of "randomness" is often confused with observations that are not fundamentally random. In the context of theoretical physics and its practical applications in cryptography and artificial intelligence, the distinction between true versus pseudorandomness is crucial in ensuring "random" sources are fundamentally unpredictable and free of bias. This experiment seeks to define and utilize a quantum source of true randomness to generate sequences of fundamentally random digits at request. Likely due to limitations in equipment and experimental approach, the results of this experiment were unable to verify vacuum fluctuations as a source of true randomness. Nevertheless, this research serves to inspire future work by examining areas in need of improved experimental design.

Introduction

The term "randomness" is associated with two significantly different concepts—phenomena that exhibit statistical randomness but conceal deterministic physical influence, and those that genuinely embody the *inherent* unpredictability associated with randomness. This distinction between true randomness and pseudorandomness is not a mere theoretical abstraction; rather, it assumes pivotal significance in shaping the reliability and security of diverse applications in theoretical science and information security.

My research aims to examine this distinction by generating a source of truly random digits for practical use and verifying their inherent unpredictability through a statistical approach. The acknowledgment that true randomness represents a valuable resource prompts an exploration of quantum sources as potential generators of sequences that transcend deterministic constraints. Quantum mechanics is most widely-accepted in the scientific community as a source of fundamental randomness. One proposed source of true randomness lies in vacuum fluctuations–a uniquely quantum phenomenon with which no statistical predictability has been observed to date (Shi et al., 2016). These fluctuations describe the temporary changes in energy that occur at the subatomic level, even in a vacuum, which is typically thought of as devoid of matter and energy. According to the principles of quantum mechanics, empty space is not as empty as the vacuum classical physics defines. Instead, it is a field of virtual particles and antiparticles spontaneously popping in and out of existence (Reynaud et al., 2001). Fluctuations arise from Heisenberg's uncertainty principle–another principle of quantum mechanics–which states that there is a limit to the precision with which certain pairs of properties, such as position and momentum, can be simultaneously known. In the vacuum, particles and antiparticles can spontaneously emerge and borrow energy from the vacuum for extremely short periods, in accordance with the uncertainty principle, before destroying each other. This activity sometimes results in the spontaneous emission of photons (Reynaud et al., 2001). In the context of this experiment, this behavior results in a random number and polarization of photons to be sourced. Despite decades of observation and statistical analysis, no evidence of physical constraints or patterns have been discovered to influence the rate of fluctuations in a subatomic vacuum, supporting the suggestion that this behavior is fundamentally non-deterministic. By relying on these fluctuations as a source of randomness and statistically analyzing the resulting digits to validate a lack of apparent patterns, we strive to validate the assumption of randomness as thoroughly as possible with available means.

Beyond just a theoretical consideration, the practical implications of this research are particularly relevant in fields where unpredictability is not just a conceptual ideal but a practical necessity. By manipulating and verifying the existence of truly random phenomena, this paper aims to support the robustness and security of systems reliant on genuinely unpredictable data streams.

Materials and Methods

This experiment consisted of two main components: a physical circuit connected to an Arduino Uno, and a program to process the input and output the results in binary form. The circuit–built on a miniature breadboard–relied on the voltage readings of two photoresistors connected in parallel. Both photoresistors received light input provided by a red laser diode powered by 5 volts, directed equally to both components through a 90-degree beamsplitter cube. Photons that are polarized parallel to the plane of incidence (horizontally at the center of the beamsplitter in this case) pass directly through. Those that are polarized orthogonal to this plane (and thus vertically polarized in this context) are deflected 90 degrees to the right. The photoresistors were placed in front of each resulting beam. Component holders were custom designed and 3D-printed to stabilize both the beamsplitter and laser in place along a level, horizontal axis. A 220-ohm resistor was placed in series with each photoresistor to allow for voltage measurement. During each iteration of the program, the laser diode was powered via a digital pin for a brief interval. At the moment the power to the laser was cut, the voltages of each photoresistor were compared–each of which was assigned a binary value of “0” or “1”–and the highest voltage reading of the two would be printed alongside the binary value corresponding to the photoresistor that provided the higher reading. If both were equal, then the function reiterated.

Results

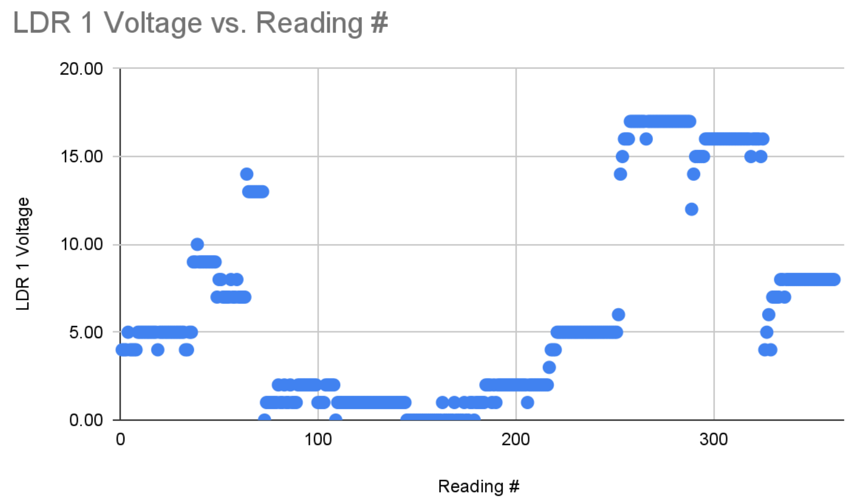

Figure 1. A graph of voltage readings from photoresistor 1 (measuring vertically polarized photons) as readings were measured.

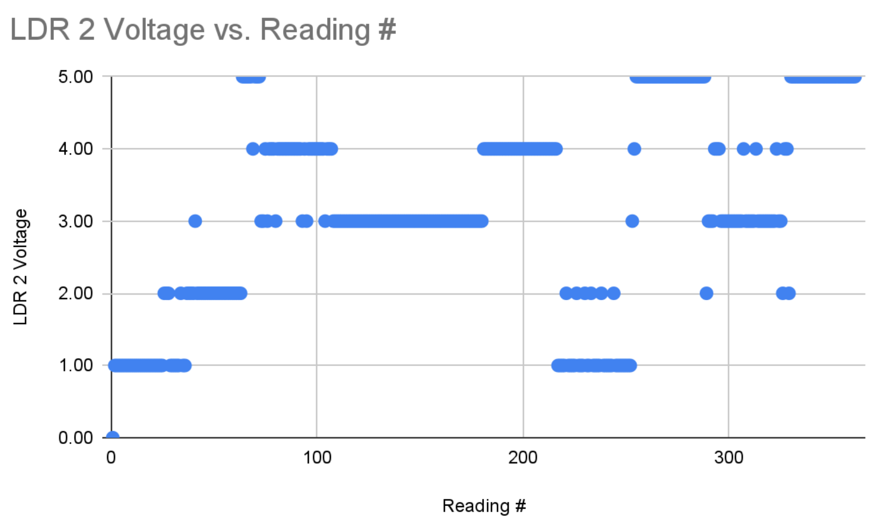

Figure 2. A graph of voltage readings from photoresistor 2 (measuring horizontally polarized photons) as readings were measured.

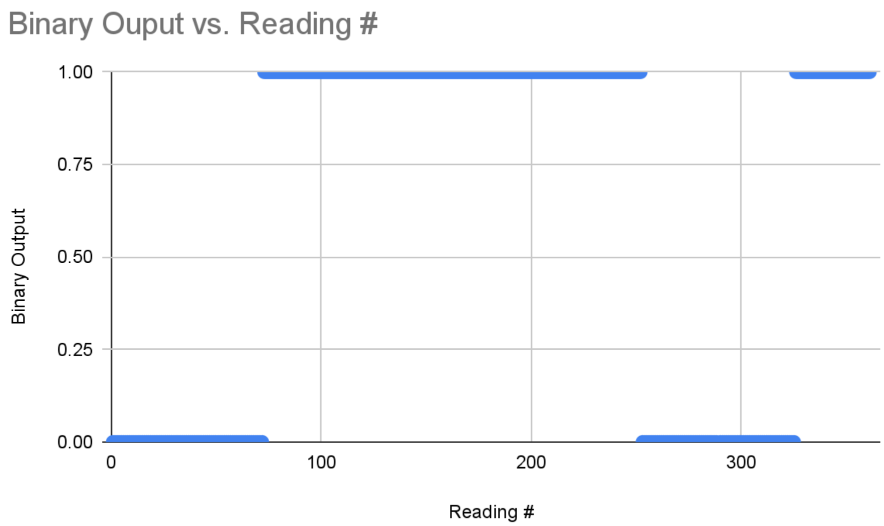

Figure 3. A graph of binary output (as either 0 or 1) as readings were measured. Binary outputs of 0 indicated photoresistor 1 read a higher voltage, and outputs of 1 indicated photoresistor 2 read a higher voltage.

In the above graphs of photoresistor (LDR) voltage versus reading number (the order of readings taken), it is evident that for each period of readings taken, the voltage of one LDR was always greater than the other. In the graph of Binary Output vs. Reading #, each streak of the same value of either 0 or 1 represents a distinct trial time period in which readings were measured. In the first trial of readings (from reading numbers 1-73), the binary output was consistently 0, indicating that LDR 1 (the LDR measuring horizontally-polarized photons) was receiving a higher number of photons, and thus reading a higher voltage. In the second trial of readings (from reading numbers 74-253), the binary output was consistently 1, indicating that LDR 2 (measuring vertically-polarized photons) was receiving a higher number of photons and thus reading a higher voltage. A similar effect is seen in the subsequent two trial periods, consistently providing values of solely 0 or 1. The effect cannot be traced to a lack of power to either LDR or differing power supply, since both LDRs provided readings above 0, were connected in parallel to the same voltage source, and individually in series with one 220 ohm resistor each. The readings were all measured in one dark room with a supposedly negligible amount of consistent ambient light coming from the perimeter of a doorway. However, although the ambient light was considered negligible during the experiment, it is possible this affected the results. This along with other sources of error will be discussed further in the following section.

Discussion

This experiment has served as an entrypoint to using quantum optics as a means of harnessing true randomness for the creation of fundamentally non-deterministic datasets. After analyzing the results and experimental setup, several key areas of improvement and sources of error have been identified. Most importantly, photoresistors have proven to be insufficient in measuring photon input. Photoresistors were originally chosen as they are easily accessible, cost-efficient, robust, and straightforward in their ability to provide voltage readings depending on the quantity of light input. After analyzing the results and further researching these components, it became evident that photoresistors display time-dependent characteristics and temperature sensitivity. These components can store photon measurements for a brief period after the input light source is removed (Louise, 2020). Although each of the readings were taken milliseconds after the laser was shut off, it is unclear what the rate of time-dependency is within each photoresistor. Additionally, minor temperature fluctuations can affect voltage readings during measurement. Warmer temperatures lower resistance and thus force voltage readings to be higher than expected (Louise, 2020). Considering their unreliability, we suggest the photoresistors be replaced with a more sensitive light-measuring component that is free of temperature and time-dependency. Photodiodes are the replacement of choice, as they are significantly higher in sensitivity and can more accurately detect small phase shifts from the incoming laser beam (Rafaelli, 2018). Additionally, joining resistors in series with the laser diode–reducing its power–should result in fewer photons reaching the detectors at once, thus preventing oversaturation and inaccurate readings. Aside from the choice of components themselves, it is also worth considering the effect of ambient lighting on light readings in either case. It is difficult to calculate and account for the amount of photons that may have contacted the photoresistors from the openings around the doorframe. In future iterations of this experiment, securing the circuit inside a light-proof container and conducting measurements in a darker room will mitigate external light interference. A combination of sensitive photodiode replacements and a light proof setting should allow the circuit to detect vacuum fluctuations at smaller magnitudes with less classical interference.

Acknowledgements

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