Simulation and Analysis of Radioactive Decay Data

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Abstract. *This project demonstrates the simulation of decay data and the subsequent analysis of the observed counts in the context of a radioactive decay experiment. The natural source of variation in this scenario is the stochastic nature of the decay process, which follows a Poisson distribution. The size of the variations in the observed decay counts depends on the decay constant and the time interval of data collection. By comparing the observed counts to the expected counts, the analysis provides insights into the accuracy of the measurement and the agreement with the expected behavior. The fitted Gaussian curve represents the uncertainty or noise in the measurement, which can be quantified by the mean and standard deviation of the observed decay counts.*

1. Introduction

Radioactive decay is a natural process by which an unstable atomic nucleus loses energy by emitting ionizing radiation. This process occurs spontaneously and can be characterized by a decay constant (rate), which determines the probability of a radioactive atom decaying per unit time. The most common types of ionizing radiation emitted during decay are alpha particles (helium nuclei), beta particles (electrons or positrons), and gamma rays (high-energy photons). Angevaare et al. (2018) investigated the long-term measurement of gamma emissions coming from beta decays using the light emitting diode to monitor the data acquisition. In addition, they characterized the stability of the experiment and show that the relevant systematics are accounted for. The decay process is often modeled using a Poisson distribution, which describes the probability of a certain number of events occurring within a fixed time interval, given a known rate of decay. For instance, Malins, Lemoine. (2022) employed a Python package to model a radioactive decay, they developed a code to obtain the analytical solution of the decay using the decay chain differential equation. This project simulates and analyzes radioactive decay data using the Poisson distribution. It first sets some parameters for the experiment, such as the decay constant (rate) of the radioactive substance, the time interval for data collection, and the total time of data collection. It then uses these parameters to generate expected counts of decay events based on Poisson fluctuations around the expected value.

2. Implementation, Results and Discussion

This code simulates and analyzes radioactive decay data using the normal distribution and Poisson distribution. Let's go through each section step by step: The code begins by importing the necessary libraries, namely NumPy for numerical operations, Matplotlib for data visualization, and SciPy's stats module to access the normal and Poisson distributions. The np.random.seed(1) line sets a random seed to ensure reproducibility of results. The decay constant variable represents the decay constant (rate) of the radioactive

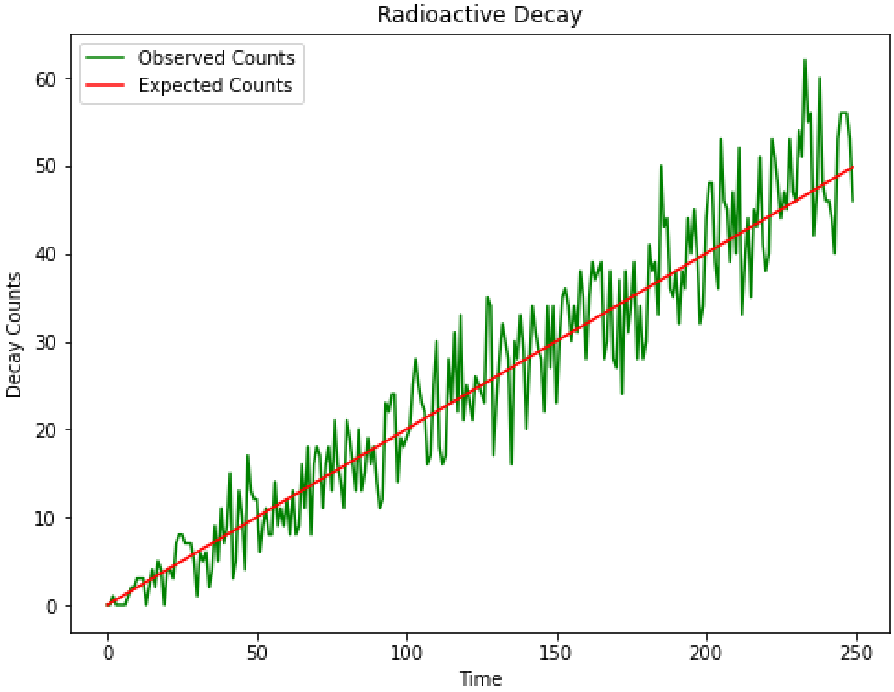

Figura 1. The radioactive decay counts against the time

substance, and time interval specifies the time interval for data collection. The measurement time variable determines the total time of data collection. Based on these values, num measurements is calculated as the number of measurements obtained by dividing the measurement time by the time interval. The expected decay counts are generated using the formula decay constant * time interval * np.arange(0, num measurements), which represents the expected number of decays at each time point. These expected counts form the basis for the Poisson distribution, where the fluctuations around the expected value model the natural stochastic behavior of radioactive decay. The np.random.poisson (expected counts) line generates random decay counts based on the Poisson distribution. To analyze the mean counts and standard deviation counts, variables are computed using the NumPy functions np.mean() and np.std() to calculate the mean and standard deviation of the decay counts, respectively. These statistical properties provide insights into the central tendency and spread of the observed decay data. The decay counts is plotted against the time where a figure is created using plt.figure (figsize (10, 4)) to set the size of the plot. The plt.plot() function is used to create two lines on the plot; one for the observed counts (decay counts) and another for the expected counts (expected counts). Axis labels, legend, and a title are added using plt.xlabel(), plt.ylabel(), plt.legend(), and plt.title() functions. Finally, plt.show() displays the plot. Furthermore, the histogram and fitted Gaussian Curve is plotted as shown in Fugure 2. The plt.hist() function is used to plot a histogram of the decay counts (decay counts) with 10 bins. The density equals to true argument normalizes the histogram, and alpha equals to 0.7 sets the transparency of the bars. The histogram represents the distribution of observed data points. Additionally, a Gaussian curve is fitted to the histogram using the norm.fit (decay counts) function, which estimates the mean (fit mu) and standard deviation (fit sigma) of the underlying normal distribution. The x array is created using np.linspace() to generate 100 equally spaced values between the minimum and maximum decay counts. The norm.pdf (x, fit mu, fit sigma) function calculates the probability density function of the fitted Gaussian distribution at each point in x. The resulting curve is plotted using plt.plot(). Axis labels, legend, and a title are added as before, and the plot is displayed with plt.show().

Finally, the output of the code provides the mean (25.4 s) and standard deviation (15.7 s) of the observed counts, which can be used to calculate the uncertainty in the measurements. These statistical properties can be used to interpret the results of the experiment and make conclusions about the behavior of the radioactive substance.

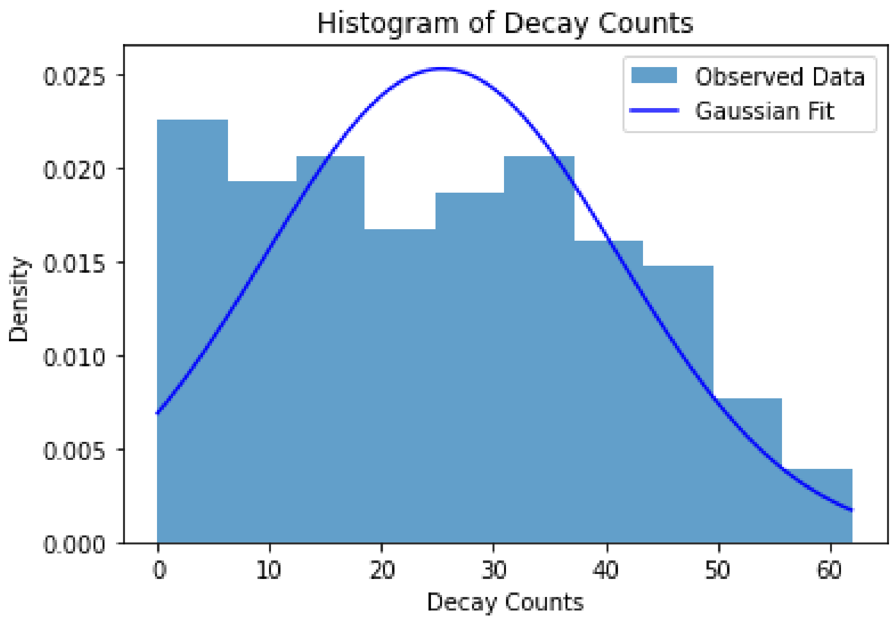

Figura 2. The histogram and fitted Gaussian Curve for radioactive decay counts

3. Interpretation

In this simulation, a radioactive substance with a decay constant of 0.2 is considered. The decay process over a range of time intervals is simulated and obtain the counts of decay events at each time interval. These counts exhibit Poisson fluctuations around the expected decay rate. The size of the variations in the measurement can be estimated using the square root of the mean counts, as the standard deviation for a Poisson process is equal to the square root of the mean. The natural source of variation in this scenario is the probabilistic nature of radioactive decay, resulting in stochastic fluctuations in the observed event counts. Measurement uncertainties can arise from sources such as statistical fluctuations, background noise, detector efficiency, or calibration errors. The size of these uncertainties depends on the specific experimental setup and the quality of the measurement apparatus. These uncertainties can be included in the model and analysis by considering the statistical properties of the measurement process, such as the Poisson distribution for counting experiments. The question being addressed in this measurement or analysis is the determination of the decay rate of the radioactive substance, which represents a model parameter. The accuracy of achieving this measurement depends on factors like the precision of the experimental setup, the duration of the measurement, and the magnitude of the natural variations. By analyzing the measured data and fitting it to a Gaussian distribution, we can estimate the mean and standard deviation of the decay counts, which provide information about the underlying decay rate and the uncertainties associated with the measurement. It should be noted that this is a simplified example, and in real experiments, additional considerations and statistical methods may be required to account for various sources of uncertainty and perform a more accurate analysis.

4. Conclusion

This project simulates and analyzes data from a radioactive decay experiment. The decay constant of the radioactive substance is assumed to be 0.2, and the time interval for data collection is 1 second. The total time of data collection is 250 seconds, so the number of measurements is calculated based on the time interval and total time. The expected counts of decay are calculated as the product of the decay constant, time interval, and an array of integers ranging from 0 to the number of measurements. These expected counts are then used to generate the actual decay counts using a Poisson distribution, which represents the stochastic fluctuations around the expected value. The mean and standard deviation of the observed decay counts are calculated using the numpy functions np.mean and np.std.

5. Reference

J.R. Angevaare et al. (2018). A precision experiment to investigate long-lived radioactive decays. Journal of Instrumentation, 13, P07011. https://doi.org/10.1088/1748-0221/13/07/P07011

A. Malins, T. Lemoine. (2022). Radioactive decay: A Python package for radioactive decay calculations. Journal of Open-Source Software, 7(71), 3318.