A Note on the Design of Experiments

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Introduction

In this note, we will speak about the general design of an experiment and some factors to be considered.

An experiment is used here to mean the deliberate causing of some physical event combined with the taking of data related to the event and the reduction of the data to useful information. This definition does not preclude the repetition of an experiment, although good practice might include iterative modifications to better accommodate the goals of the experiment.

A properly designed experiment will allow a maximum of useful information to be obtained and a low probability of lost data,

Background

The fundamental process of data acquisition, reduction, and analysis is as follows:

- A physical event occurs.
- A transducer changes some physical manifestation of the event into a form that may be recorded.
- A record is made.
- The record is examined, and perhaps transformed in some way, and useful information is obtained.

In an ideal world, we would be able to directly record every physical manifestation of any event with perfect fidelity, assign correct values, and obtain all the information that is desired and available. In the real world, as you might expect, things are a bit different.

Let us examine a few examples that will illustrate some of the problems.

Investigator Desires To Find Out How Loud a Firecracker Report Is

Simplest Method

1) Light one firecracker.
2) Retire to a safe distance.
3) Listen to report of firecracker.
4) Record in notebook—"medium loud".

Possible Advantages and Problems of Simplest Method

1) Quick, easy, inexpensive.
2) Firecracker used may not be representative. What if it fizzes and spins around on the ground? Does the investigator conclude that firecrackers don't make a report?
3) How does the distance affect the noise? What if the investigator knows that this firecracker will not hurt his fingers and holds it up to his ear? What if the safe distance is arbitrarily set to be 10,000 meters?
4) Does the transducer (the ear of the investigator) affect the result? What if the investigator is deaf? What if the investigator is only partially deaf?
5) How useful is the result?

More Complex Method

1) Light 25 randomly selected firecrackers from the group of interest at 1-minute intervals.
2) Retire to a distance of 10 meters.
3) Panel of 25 firecracker aficionados, also located at 10 meters from the firecracker, listen to reports.
4) Each member of the panel assigns a numeric value to the perceived loudness of each report.
5) Write the individual reported values in notebook.

Possible Advantages and Problems of the More Complex Method

1) Probably reasonable representation for this type of firecracker.
2) Probably, but not necessarily, a good cross-section of transducers.
3) Was the distance appropriate for the type of firecracker?
4) Was the time interval sufficient to allow the transducers to "re-zero"?
5) How does one calibrate each (set of) transducer(s), such that each value reported may be compared?
6) How does one report the results? What does "7.28" mean?

More Sophisticated Modern Method

Pre-test Section

1) Gather available equipment to acquire, record, and analyze the firecracker report.
2) Investigate the strengths and limitations of the equipment.
3) Perform at least a minimal analysis of the interactions between the physical event and the sequent measurements.
4) Perform a minimal experiment (pre-test) to test the validity of step 3, and adjust as required to stay within the calibration limits of the equipment.

Sample notes from pre-test investigation of the equipment available:

Microphone: linear response 60–140 dB; frequency response 5 to 30 KHz; output from microphone amplifier 0.01 V/dB.

Values for four firecrackers, measured at 2.5 meters, were between 110 and 120 dB.

Bits of debris were found at 4 meters.

Digital oscilloscope (DSO) has input ranges of 0–1 V, 0–5 V and 0–10 V; a maximum of 4000 data points per trace; and time per point rates of 1, 2, 5, 10, 20, 50 × 10^{-6} second.

Computer still has 100 MB of storage space available.

Test Section

1) Set up firecracker test stand and calibrated microphone at 5 meters horizontal distance, and 3 meters from ground. This will help avoid overloading microphone and possible damage from debris, set DSO to trigger from sound with a pretrigger of 2000 points, a sensitivity of 2 V full scale, and a time per point of 10^{-6} seconds.
2) Fire and transfer to separate computer files the results of firing 20 randomly selected firecrackers from the group of interest.
3) Assign time and dB values to each data point recorded.
4) Obtain the statistics, and "interesting information" for each test, and for the test aggregate.
5) Record the statistics and waveforms obtained in notebook.

Why did we do this?

From the capabilities of the equipment and the preliminary test, the following decisions were made:

1) The microphone had an upper frequency response of 35 KHz, so that data would have to be taken at a minimum of 70,000 data points per second to be within the Nyquist limit, or an analog filter would have to be interposed between the microphone and the DSO.
2) The next higher data rate available above 70,000 points/second was 100,000 points/second (10^{-6} seconds/point), which, for a maximum data collection length of 4000 points, would allow a data collection time of 0.040 seconds.
3) The report of a firecracker seemed to take no more than 0.005 second, so that ± 0.020 seconds from the trigger point would be more than enough data.
4) The fuses on firecrackers are not sufficiently accurate in timing to allow triggering from fuse ignition, so data acquisition was triggered from the sound itself.
5) Since we expected some variation in sound, we set the sensitivity of the DSO to the next available range which would allow recording

any expected peaks without clipping and without sacrificing too much sensitivity.

6) Data was transferred to a computer for semi-permanent storage because we don't know ahead of time what we might see, unexpectedly, in the data.

Since the cost of equipment is always a consideration for both the professional and non-professional, the author suggests that whatever money is available be spent as wisely as possible. In general, the author believes that this end is best achieved by obtaining, to the extent possible, equipment that is as flexible and precise as possible to allow for future uses that may be unseen at the present.

At the present time, with judicious selection, it is possible to obtain analog-to-digital data acquisition cards for use with an inexpensive computer. Many of these cards have multiplexed inputs for multiple channels of single ended or differential input at cumulative rates well exceeding 100,000 samples per second with a 16-bit precision and cost less than US$500. Other cards may offer increased precision, higher data acquisition rates, on-board signal conditioning, and other possibly useful features. It will usually be found that a working knowledge of programming will greatly benefit the investigator's equipment budget.

Such a card and a very basic computer will allow many different sorts of potentially accurate measurements to be made. Furthermore, the data collected from such a system may be analyzed, massaged, tweaked, folded, spindled, and mutilated as much as the investigator desires, without ever losing the original data.

An analysis of the entire system to be used in a particular experiment may also yield a way to achieve acceptable accuracy without resorting to other expensive equipment and calibration techniques.