ME231
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Digital Data Acquisition

Edmundo Corona ©

The latter part of the 20th century witnessed the birth of the "computer revolution." The development of digital computer technology has had a large impact in both our everyday lives as well as in the engineering profession. In the latter, the formidable increase in computing power since the 1950's allowed the analysis of many problems which were intractable previously. The influence of the computer did not stop there but extended into the areas of design and, yes, measurements. In fact, the currently favored methods used in data acquisition are vastly different from those used as recently as the 1970's.

The main reason that digital computers are widely used in measurements is that they greatly facilitate the handling of data and allow calculations to be performed on the data to be very fast and sophisticated. On the other hand, the more sophisticated the tool, the more careful and technically proficient the users must be to use it properly. Incompetence in the use of computers have given rise to sayings such as "garbage in, garbage out," or "to err is human, to really mess things up it takes a computer."

A couple of final comments before we launch ourselves into the world of digital data acquisition. First, when we talk about digital data acquisition we are not only referring to the use of desktop computers, but in general to the use of digital processors or chips. Such chips may be installed on airplanes, cars, toasters, etc. Second, to know what pitfalls may be awaiting us when we use digital devices in measurements, we must first take a step back and review the analog world.

Analog Signals and Discretization

An analog quantity is one which is continuous and smooth. For example, a common glass bulb thermometer indicates temperature by the length of a column of mercury. As the temperature changes, the column of mercury changes smoothly. You might argue that if you could measure the length of the column to an infinite number of significant digits, you could detect infinitesimally small changes in temperature. Furthermore, if you could make a continuous time record of temperature, you could tell what the temperature was at any instant in time, even at two times within an interval smaller than one billionth of a second apart. The resulting temperature reading would be continuous in time and would possess infinite resolution. In other words, it would be analog.

A variety of devices to display and/or record analog signals have been invented. They were heavily used prior to the development of digital data acquisition systems. They included dial-and-needle instruments, tape recorders, chart recorders, etc. In movies about earthquakes, they invariantly show chart recorders. When the earthquake strikes the scene will show the recorders' pens tracing lines of great amplitude on paper moving under them. That's more exciting than showing a digital display showing numbers alone. Don't you think so?

Unfortunately, digital computers and devices, in spite of all their processing power, have one fault. They have limited memory. Therefore, they can not handle analog signals, which carry an infinite amount of information. As a result, analog signals must be *discretized* before they can be sent to a digital device. The Webster's dictionary defines discrete as "consisting of distinct or unconnected elements, taking on or having a finite number of values." The discretization process in data acquisition systems occurs both in time and value as explained below.

Discretization in Time

The discretization of a signal in time is called "sampling." The most common example is the movies. We know that a movie is actually a series of still photographs which, when played at a reasonably fast speed, gives the impression of motion. In this example, the analog signal is reality, which happens smoothly. The movie is discrete in the sense that it consists of a finite number of frames, each containing one instant in time. Events that happen between frames are lost forever!

Similarly, sampling of a signal consists of measuring the signal only at specific instants of time instead of all the time. For example, Figure 1(a) shows an analog signal. If the signal is sampled at time intervals δt then the sampled record would look as shown in Fig.1(b). Note that the "dips" in the curve between times t_3 and t_5 have been missed. We will never be able to recover those features of the signal from the discretized record. In summary, data is always lost during sampling. Therefore, it is important to always make δt as small as necessary to capture all the features of interest in the signal.

Discretization in Amplitude

The discretization of the amplitude of a signal is sometimes called "quantization." While discussing the thermometer example above we noticed that analog signals have infinite resolution, even infinitesimal changes in the measured values

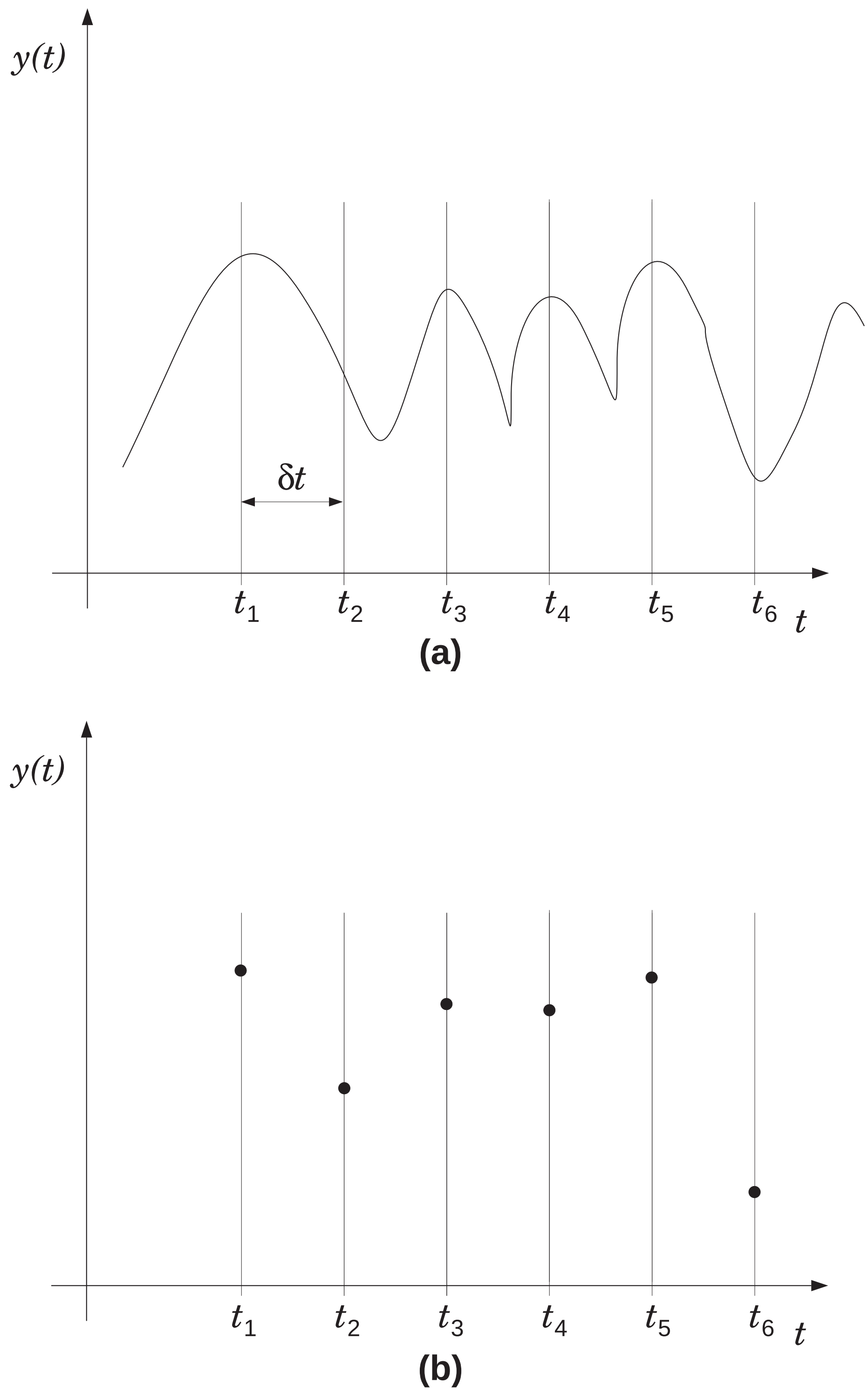

Figure 1: Discretization in time. (a) Analog signal. (b) Discretized signal.

produce infinitesimal changes in the output. Due to memory limitations, digital devices can not achieve infinite resolution and must chop some of the information off the signal. One obvious example of this process can be seen at the grocery store when you purchase eggs. We know that if we took all the hens in the world and measured the volume of each egg they could possibly lay, we would end up with an analog quantity. In other words an infinite number of values for the egg volume would exist. Yet, at the grocery store, eggs are classified into regular, large, extra-large and jumbo. Only four categories in which to fit all egg sizes! In other words, all eggs with volume in a certain range are just called "large." Talk about an identity crisis for the eggs!

Similarly, quantization of a signal consists of measuring its amplitude, but being able to assign the amplitude values to a finite number of "boxes." For example, Fig. 2(a) shows an analog signal as in the previous figure, except that the y axis has now been partitioned in finite intervals labeled $y_1 \ldots y_5$. At the times $t_1 \ldots t_5$, the value of the signal is assigned to the box in which it happens to reside at that time. After discretization, all the information we have left is the thick lines shown in Fig. 2(b). All we know now is that the signal passed through the box y_5 at time t_1, box y_3 at time t_2 etc. We no longer know the exact value of the signal at all times. If you think about it, we have lost an infinite amount of information during discretization. The analog signal, however, contained infinite information. This is one of those lucky situations where infinite minus infinite is not zero, but a finite number. It will hopefully be large enough to complete the tasks we hope to accomplish.

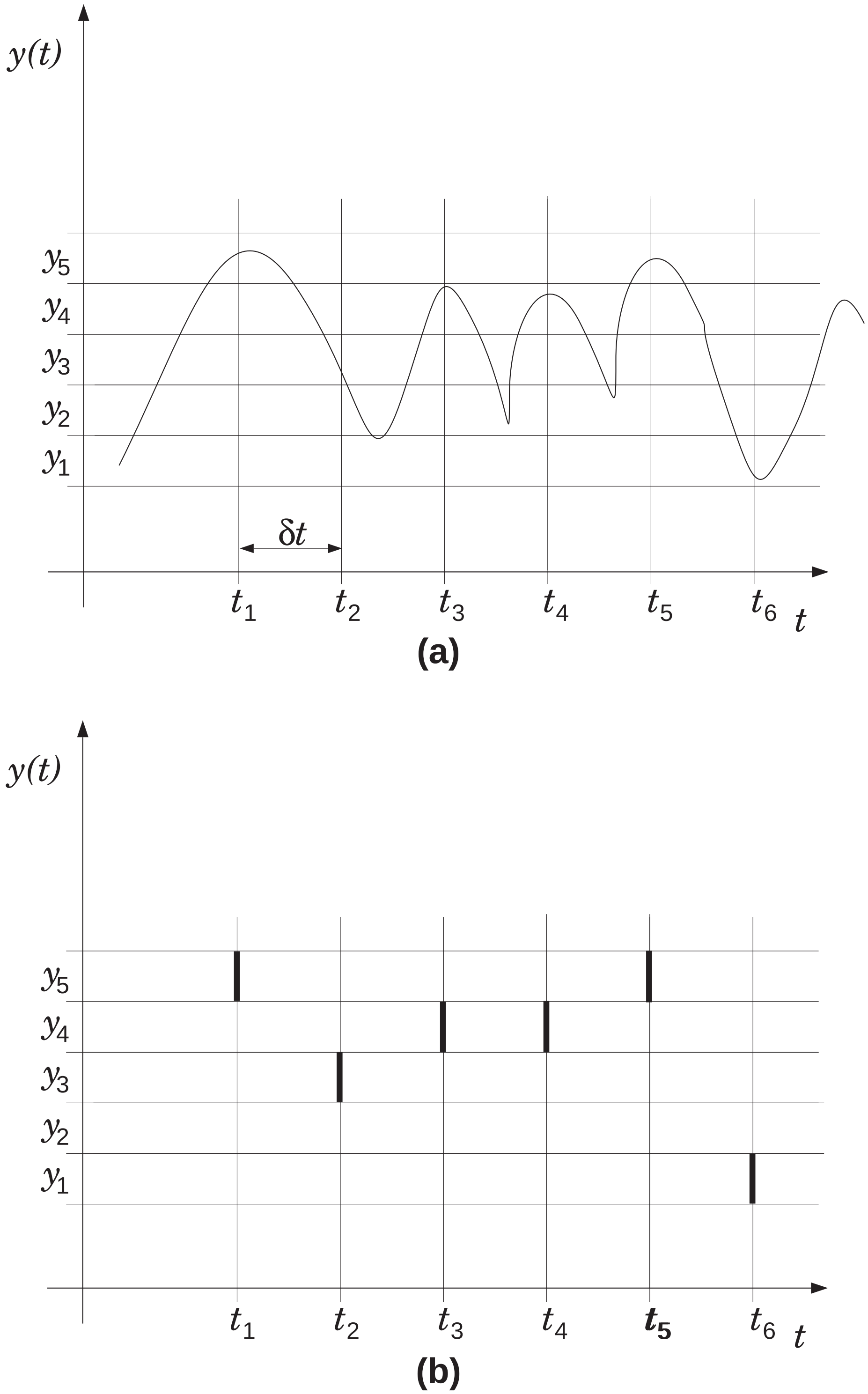

Figure 2: Discretization in amplitude. (a) Analog signal. (b) Discretized signal.

Exercises

1. Consider an analog signal of the form $y = t^2$ in the domain [0,5]. Discretize the signal in time and value using $\Delta t = 0.5$ and $\Delta_y = 5$. Name the y boxes after their mean value, ie the box [0,5] as 2.5, the box (5,10] as 7.5, etc. Tabulate the results and then plot them in the manner of Fig. 2.

2. In some Western movies, when the scene involves a fast moving carriage, it appears the at the spokes of the wheels are turning backwards. Why? If you have not observed this, think of a wheel with a single radial line drawn on it. If you make a movie of the rotating wheel, would it be possible to make the wheel appear to be rotating backwards or, in other words, in the direction opposite to the actual rotation? How?