Timing a Ballistics Experiment

Many experiments require several processes to coincide with an event of unknown timing. Photographing a projectile in flight, for example, requires accurate coordination of the camera, sensors and flash lamps to capture a projectile of unknown speed.

In this study, we'll examine various ways to control experiments of this nature using the LabSmith LC880 Programmable Experiment Controller. First, we'll base our timing on an assumed muzzle velocity. Next, we'll determine the projectile's speed in flight and time events accordingly.

Static Timing

For his famous photographs which captured a bullet in flight, Harold Edgerton used a microphone at the muzzle of a gun to trigger his camera and strobe lamps. We would, instead, use photodetectors to sense the bullet as it reaches a known position. If we know the gun's muzzle velocity, we can time the flash lamps and camera with some degree of accuracy.

Figure 1a shows the arrangement for this experiment, while Figure 1b shows its timing diagram. The bullet velocity is assumed to be a constant 300 m/s, and the camera is positioned exactly 16 m from a photosensor. At $t = a$ the bullet passes the photosensor, which sends a signal to the first input (in1) on the LC880. The time for the bullet to reach the camera is:

$$\frac{16 \, \text{m}}{300 \, \text{m/s}} = 53.333333 \, \text{ms}$$

We can designate Channel A of the LC880 to open the camera shutter. The channel will operate in Delayed Pulse mode: after
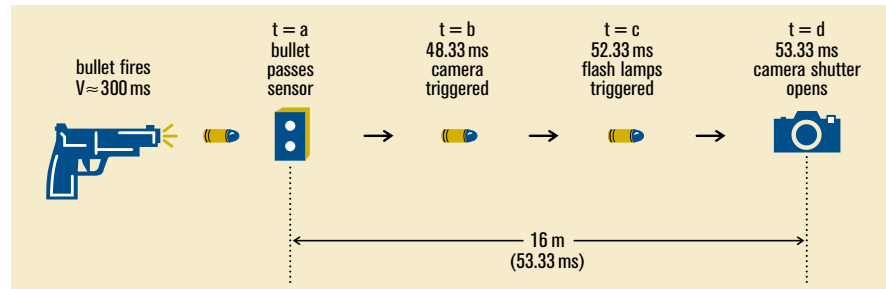

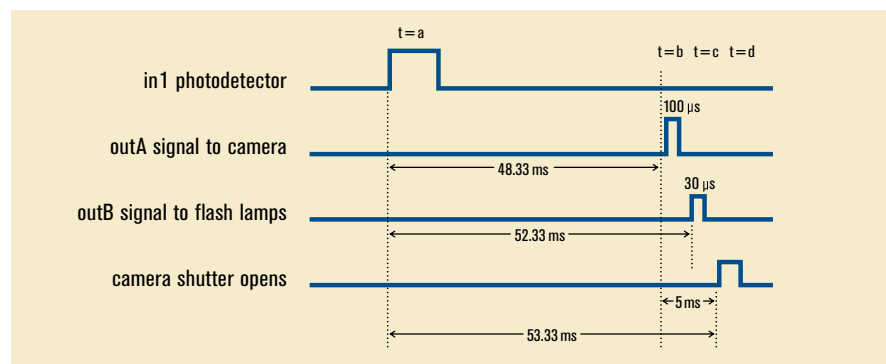Figure 1a: Schematic diagram of a static timing ballistics experiment.

t = a
bullet fires
V ≈ 300 ms
bullet passes sensor
t = b
48.33 ms
camera triggered
t = c
52.33 ms
flash lamps triggered
t = d
53.33 ms
camera shutter opens
16 m
(53.33 ms)

Figure 1b: Timing diagram for the static timing experiment.

t=a
in1 photodetector
t=b t=c t=d
outA signal to camera
100 µs
48.33 ms
outB signal to flash lamps
30 µs
52.33 ms
camera shutter opens
5 ms
53.33 ms

Channel A:
Delayed pulse: Delay after trigger 48.333333 ms then pulse output 100.000 µs.
Triggering options: Trigger on rising edge. Trigger once between clears.
Trigger Input Logic: inA = in1;

Channel B:
Delayed pulse: Delay after trigger 52.333333 ms then pulse output 30.000 µs.
Triggering options: Trigger on rising edge. Trigger once between clears.
Trigger Input Logic: inB = in1;

Figure 1c: LC880 programming for the static timing experiment.

receiving a signal at input 1, it will wait a defined period before sending a signal to output A. A second Delayed Pulse on Channel B will fire the flash lamps.

When triggering the camera we must account for the 5 ms required to open its shutter. The delay on Channel A must therefore be set to 48.333333 ms. Similarly, the flash lamps pulse 1 ms after the trigger signal, so we set the delay on Channel B to 52.333333 ms. (This is much

more precise timing than is required, of course). The timing modes for each channel can be set using dialog boxes and C-style syntax commands. The LC880 program for this experiment appears in Figure 1c.

Dynamic Timing

Static timing relies on an estimated muzzle velocity, which might be good enough for the purposes of photographing a bullet.
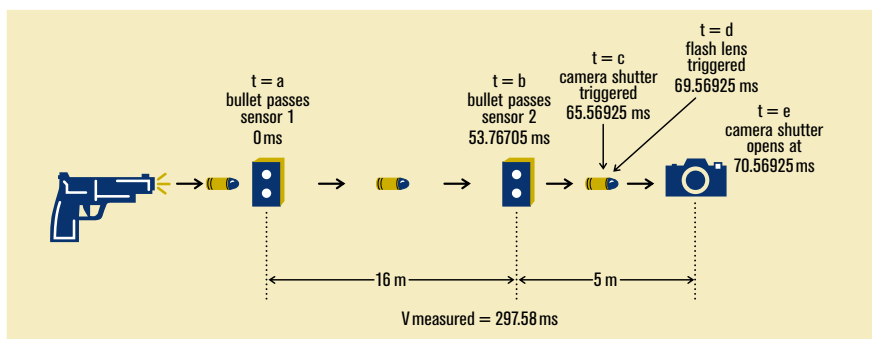
Figure 2a: Schematic diagram of a dynamic timing ballistics experiment.
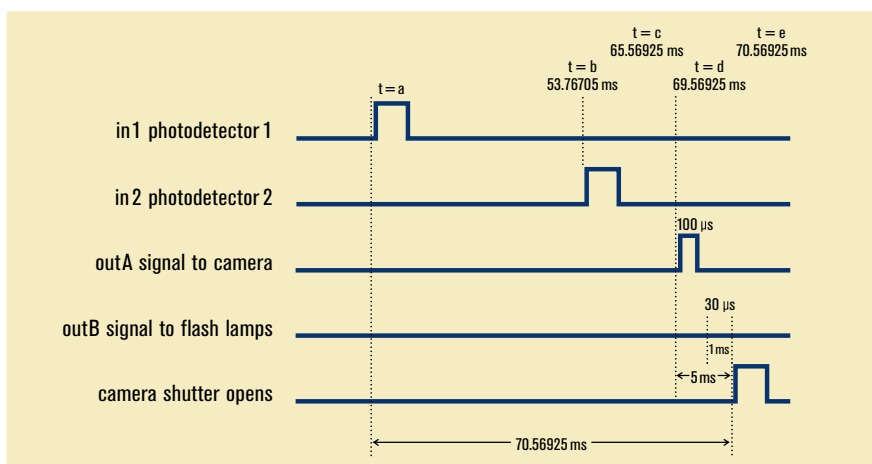

Figure 2b: Timing diagram for the dynamic timing experiment.

Channel A:
Dynamically delay pulse: Multiply delay by 5/16, Subtract 5.000000 ms from this value. Pulse the output after the calculated delay for 100.000 μs.
Trigger Input Logic: inA = in1 or in2;

Channel B:
Delayed pulse: Delay after trigger 4.000000 ms then pulse output 30.000 μs.
Triggering options: Trigger on rising edge.
Trigger Input Logic: inB = outA;

Figure 2c: LC880 programming for the dynamic timing experiment.

But in most experiments the cost incurred per run demands correct timing on the first try, and every time thereafter.

The best method for timing this type of experiment is to determine the actual velocity of the projectile during each run, then to trigger all events from that known value. To do so, we can employ a unique feature of the LC880: Dynamically Delayed Pulse mode. In this mode, the bullet passes two sensors. The LC880 determines the bullet's velocity based on the time delay between signals from the two sensors, then triggers the camera and flash lamps after appropriate delays. **Figure 2a** shows the dynamic measurement setup, while **Figure 2b** shows the timing diagram. The time of flight from the second sensor to the camera is:

$$t_{flight} = \left[\frac{t_{sensor2} - t_{sensor1}}{distance\ between\ sensors} \right] [distance\ from\ sensor2\ to\ camera]$$

Channel A will now operate in Dynamically Delayed Pulse mode to trigger the camera. In the settings for Channel A you'll specify the ratio:

$$\frac{Distance\ from\ second\ sensor\ to\ target}{Distance\ between\ two\ sensors}$$

This ratio is expressed in either the form N/16 or 2^N, where N must be an integer. For this reason we positioned our sensors 16 m apart, with the camera set 5 m further away (N=5). Dynamic delay mode also allows us to apply an offset (-5 ms) to give the shutter time to open.

Channel B, which fires the flash lamps, can remain a simple delay, now triggered by the output of Channel A rather than input 1. Channel A will send an output pulse 5 ms before the bullet reaches the camera. Since the flash lamps need to fire 1 ms before the bullet is in position, the delay on Channel B should be 4 ms.

The LC880 program for this experiment appears in **Figure 2c**. Using dynamic timing, the camera shutter will open at the right time regardless of the bullet's actual speed. The only remaining uncertainty is the amount by which the bullet slows down in flight. If this uncertainty is too high, we could account for the deceleration by adding a third sensor and a second dynamically delayed channel.

Conclusion

The LC880's unique timing modes and combinatorial logic allow for quick programming of complex experiments. Though this simple bullet experiment unfolds at millisecond speeds, the programming process remains the same for more complicated experiments with nanosecond-scale timing. Whether controlling a shock tube, a PIV study, or a 2-pulse laser experiment, the LC880 is an indispensable tool for fast project development and reliable results.

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