EPOCH TIMING FOR LASER RANGING

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ABSTRACT

The well established advantages of epoch timing are reviewed in the light of recent and iminent developments in laser ranging hardware. The capability of asymetric Stop-Start time interval measurement techniques to meet the emerging demands for timing system precision, accuracy, and event rates is questioned. The ability of systems using epoch timing to adapt to the new technology and meet the highest performance specifications is emphasised.

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1. Introduction

The advantages of epoch timing for laser ranging have been known for some time. Some of the earliest timing equipment specifically designed for laser ranging used epoch timing principles (e.g. the 'Maryland' event timer).

The principal advantages of epoch timing have been:

1. Measurement symmetry for START and STOP.

2. Capability to accommodate many shots in flight with a single instrument (i.e. multiple-stop capability).

3. Precise epochs are produced as well as range measurements.

Recent developments have highlighted these advantages as well as throwing light on some previously undetected advantages.

2. Epoch Timing Principles

A epoch timing system measures range by determining the epoch of the transmission and reception of the laser pulse, and obtaining the difference by subtraction.

An epoch timing system can be constructed from commercial electronics modules, since all that is required is a scaler/counter and a time interval unit (TIU). If the scaler and TIU are properly chosen, the epoch precision is the precision of the TIU. The specification for these 2 components are that the maximum count of the TIU must be greater than the period (1/f) at which the scaler is clocked. The scaler is simply latched by the event, which also starts the TIU, which is stopped by the same clock pulse which clocks (increments) the scaler. For example, the original (1974) Orroral LLR timing system consisted of a 10 MHz scaler, which, when latched, gave 100 ns precision epoch. The event which latched the scaler also started the 1ns precision TIU, which was stopped by a 100 KHz pulse train, giving a maximum count of 10 microseconds.

The epoch is given by

$$E = L + (c-t)$$

where L = epoch latched in scaler
c = maximum count of TIU
t = TIU measurement

In practice the epoch E is formed in a minicomputer which first truncates L to eliminate least significant digits which would overlap (c-t). If the STOP pulse train going to the TIU is not in phase with the latch clock pulse to better than the precision of the TIU, then additional adjustments need to be made to E.

The epoch E will be absolutely accurate only to the extent that the frequency standard which supplies the latch clock/TIU stop is absolutely accurate. If the clock rate is known, then the epoch accuracy can be upgraded in post-processing. The range measurements derived from these epochs will have a precision approximately equal to 1.4 times the epoch precision plus the frequency standard's error over the measurement interval.

The major difficulties in epoch timing systems are:

1. Overlapping of START and STOP events in TIU.

2. Perfect recombination of E and (c-t) to give precise epoch.

The overlapping of START and STOP events in the TIU will generally cause errors. Some systems employ two TIUs with one TIU having its STOP channel input frequency 180 degrees out of phase with the other, so that overlap can be avoided. This of course introduces more calibration complexity, but has been successful. An alternative is to make the TIU input pulses very short, and the maximum count very long, and accept overlaps. For example if the pulses were 4 ns wide and the max count 1000 ns, only 0.4% of measurements would be affected. Lengthening the max count also makes combining the TIU and scaler readings simpler, as more overlapping digits occur for longer counts, and the software algorithm for combining the two numbers into a single epoch is simpler.

3. Recent Developments

Laser ranging systems now routinely operate with a single-shot precision of 5 cm. Soon 2 cm single-shot precisions will be routine, based on new laser, receiver, and timing system technology. The precisions required by the new laser ranging systems may demand the adoption of epoch timing techniques.

An acceptable standard for ranging timing systems for the next 5 years is likely to be 30 ps (RMS) accuracy in range over 100 ms ranges, and 50 ps over lunar ranges. It is now relatively easy to acquire or even construct a TIU with 20-30 ps precision. However very few available designs will maintain this precision over more than a few microseconds. One exception, the HP5370 series TIU, limits the rate at which the laser can be fired to 5 Hz once the max count exceeds 50 ms.

Thus the newer technology in TIUs may be applicable only as the vernier, or as an add-on, to an existing measurement system. Since epoch timing scalers can easily run up to 100 MHz, giving a TIU max count requirement of 10 ns, minimal demands are placed on the TIU in this regard by epoch timing. That is, epoch timing systems are ideally suited to take advantage of high precision, short count TIUs.

An additional problem for conventional systems using direct time interval measurements to measure range arises from temperature drift of TIUs. It has recently been discovered that the HP5370B shows a measurement bias of 10 ps per degree Celsius. Other TIUs show similar biases. The error, which is systematic, does not depend on the length of count, and thus is removed entirely if the TIU is used as the vernier for an epoch timing system, since the error will occur in both epochs, and cancel out in the formulation of a time interval by subtraction.

The development of solid-state pumping for Nd:YAG lasers raises the possibility of significant improvements in laser efficiency, and may lead to higher repetition rate capabilities well beyond the present 10 Hz. At 200 Hz repetition rates, even the lower satellites will require multiple shots in flight. If recent developments in detector technology lead to 1 micron ranging systems, even higher rates could be required. Only epoch timing techniques can meet these event rate specifications. (The data acquisition and control specification is not considered here.)

Finally, new streak cameras are now available which allow 2-D scanning of the electron beam. If such a streak tube was to be integrated with a 2-D CCD array of large dimensions, then it is conceivable that it could be used as a picosecond precision vernier for an epoch timing system. If the 2-D scanning algorithm is correctly specified, it is possible to use a large proportion of the addressable space on the CCD to give an unambiguous, picosecond precision epoch readout over long periods (up to 10 ns, i.e. 10 ns maximum count). It seems unlikely that this ultra-high precision development will integrate naturally with timing systems other than epoch timing systems.