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Canoe slalom timing accuracy with photobeams

1. Summary

Canoe slalom race results are presented with a resolution of 1/100th of a second. The runtime accuracy however, when measured with photobeams, is not that good. As a consequence rankings based on runtime differences of less than 0.2 second have a chance component. Of the top rankings 30% have a runtime difference less than 0.2 second.

To attain the required accuracy for slalom measurements of 1/100th of second, timing cameras should be considered as the main measuring system. Additionally the slalom rules should define more precisely as to which part of the body breaking the start or finish line counts as start or finish moment.

2. Introduction

This paper discusses the accuracy of photobeam measurements for canoe slalom races. With the top slalom races, runtimes very often differ less than a few tenths of a second. The next graphic shows the runtime differences of the 2012 Worldcup Slalom races. (K1M Finals).

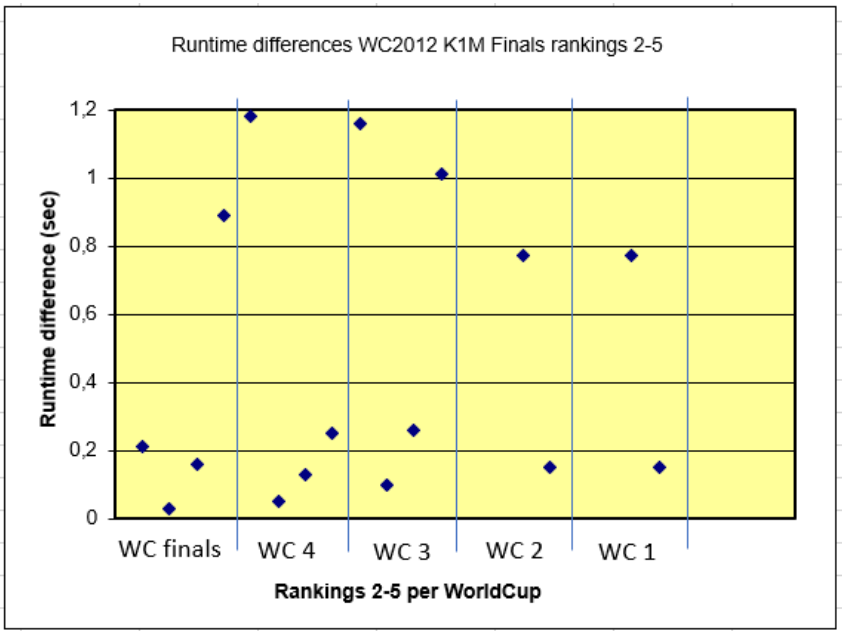


Figure 1 - Runtime differences Slalom World Cup races 2012

The graphic shows that about 30% of the top-5 runtimes is less than 0.2 sec apart. This paper will show that differences less than 0.2 sec are within the inaccuracy range of photobeam measurements. As a consequence rankings based on runtime differences of less than 0.2 second have a chance component.

Timingteam conducted comparative measurements with single and dual beam photobeams, against timing camera measurements. This paper discusses the results.

3. The Canoe Slalom rules

The ICF Slalom rules 2012 state the next requirements for timing:

- 33.1 The time of a run is measured from: The time that the competitor's body or electronic device (on body or boat) breaks the start line to the time when the finish line is broken by the competitor's body or electronic device (. ..) .
- 33.2 Timing of each run must be accurate to at least 1/100th of a second, and the results must be reported to the nearest 1/100th of a second.
- 41.12.1 Timing at World Championships must be carried out both by a photoelectric system and back up time system. In any case, the body of the competitor must be used to both start and stop the clock (see Rule 33.1).
- 41.12.2 In the calculation of results, the photoelectric system has priority. In the event of failure of the photoelectric system, the backup times are used.

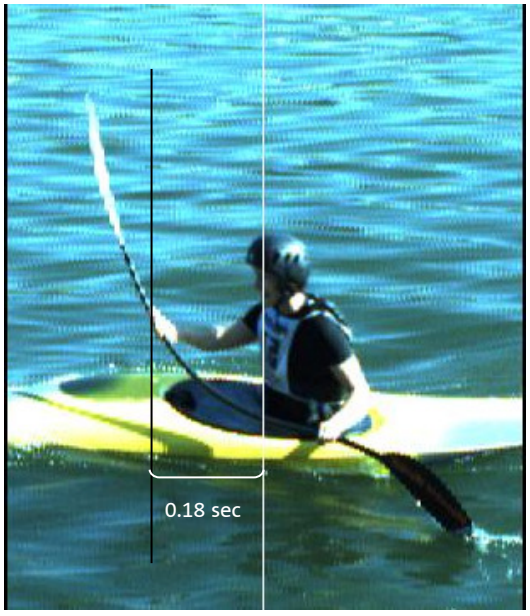
Summarizing, the slalom rules state:

- the runtime must be measured with an accuracy of at least 1/100th of a second.
- the start and finish moment is defined per when the body of the athlete crosses the start- respectively finish line.
- for World Championships the measurement must be carried out by a photoelectric system.

The rules do not define what a photoelectric system is. In practice this is a single photobeam. When the beam gets interrupted, it provides a timing impulse to an electronic clock. The clock delivers a timestamp of the moment it receives the timing impulse.

4. Photobeam measurements checked with timing camera

The photograph on the right is created with a timing camera. This is not an ordinary photograph. The picture is composed of more than 100 slices of a few pixels wide. (This also explains the strange form of the paddle).



Each slice shows a picture of just the finish line. All these slices in a sequence show what happened on the finish line during about a second. The time each slice was taken is coded into the slice. So each vertical line provides a picture of the finish line at that time. By selecting a slice, you obtain the time the slice was taken.

The timing camera was used to check the accuracy of photobeam measurements. The photobeam times were compared with the camera times. The differences were analyzed on the timing photographs, to determine what the object was on the finish line when the photobeam fired.

More than 80% of the photobeam finish times were 0.02 up to 0.18 seconds shorter than the timing camera times. These shorter times could be attributed on the timing photographs to the paddle, hand or arm as the object that interrupted the photobeam.

On the average (n=40) the premature interruption was 0.061 sec with a standard deviation $\sigma = 0.055$ sec.

(We observed more extreme cases of premature photobeam interruption in the timing photographs where it were the blade of the paddle, the tip of the canoe, or a splash of water that interrupted the photobeam. This happened with turbulent water conditions at the finish line.)

From the timing camera observations we calculated the standard deviation of finish timestamps from photobeam measurement as $\sigma_{measurement} = 0.055$ sec. This standard deviation applies also for the start timestamp, assuming the start is measured with photobeams too .

As the runtime is calculated from finish time minus start time,

then the standard deviation of the runtime is calculated as $\sigma_{runtime} = \sqrt{(\sigma^2_{meas\ start} + \sigma^2_{meas\ finish})} = \sigma_{meas} * \sqrt{2}$,

giving $\sigma_{runtime} = 0.055 * \sqrt{2} = 0.078$ sec. [Ref. Wikipedia on error propagation].

The 95% reliability interval of the **runtime** is $\pm 2 * \sigma_{runtime} = \pm 0.156$ sec.

The ranking is based on the runtime difference, i.e. the subtraction of two runtimes, i.e. the subtraction of 4 measurements.

This makes the $\sigma_{difference} = \sigma_{meas} * \sqrt{4}$ is $0.055 * 2 = 0.11$ sec.

The 95% reliability interval of the **runtime difference** is $\pm 2 * \sigma_{difference}$ is ± 0.22 sec.

To be 95% certain that a ranking is correct, runtimes must be at least 0.22 sec. apart. With this reliability interval, a runtime difference of 0.1 sec has a chance of 16% of being wrong ranked. A runtime difference of 0.01 sec has a chance of almost 50% of being wrong ranked.

5. Accuracy and Measurement resolution

The slalom results are presented in most cases with a resolution of 1/100 sec. The electronic clocks used for timing have good stability and have a resolution of 1/10000 sec. But a high resolution does not create accuracy by itself.

Accuracy of a measurement is defined [Ref.Wikipedia] as the deviation from the real value. The real value for a start or finish time is defined by the body of the participant crossing the start or finish line. But the precise measurement of this value is hampered by the situation that the photobeam cannot discriminate between de paddle, arm, head or body that is interrupting the photobeam.

As argued above, the 95% reliability interval of runtimes calculated from photobeam measurements is not better than ± 0.156 sec.

Therefore the presented 1/100 resolution on the race results is false accuracy.

5.1. Required precision of measurements

We can do the exercise above the other way around to calculate the required measurement accuracy, to obtain the required runtime accuracy.

If a ranking on 1/100 resolution is to be 95% reliable, $2 * \sigma^{runtime\ diff} = 0.01$ sec.

This makes $\sigma^{runtime\ diff} = 0.01 / 2 = 0.005$ sec.

As the runtime difference is calculated from 4 measurements,

the required $\sigma^{meas} = \sigma^{runtime\ diff} / \sqrt{4} = 0.0025$ sec.

With the a σ^{meas} of 0.0025 the runtime accuracy $\sigma^{runtime} = \sigma^{meas} * \sqrt{2} = 0.0035$ sec. This is well within the required runtime accuracy of 0.01 sec according to the slalom rules.

The required σ^{meas} corresponds with a timing camera frame rate of 400 FPS or higher. So a timing camera with a frame rate of 400 FPS on both start and finish would provide the required accuracy for runtime measurements.

6. Dual beams

As the single photobeam runtime measurement accuracy is impaired by premature interruption of the photobeam by paddle or arm, the idea is that dual beams may solve this problem. Timingteam constructed a set of dual photobeams with cell distance of 17 cm. The dual beams were vertically positioned. We did a comparative measurement against a timing camera.

The conclusion is that dual beams do effectively eliminate the premature interruption of the photobeams by paddle or arm. The measurement accuracy of dual photobeams improves to $\sigma^{dual} = 0.029$ sec.

This makes $\sigma^{runtime}$ is $0.029 * \sqrt{2} = 0.041$ sec. The 95% 2σ runtime reliability interval is ± 0.082 sec.

The $\sigma^{diff} = 0.029 * \sqrt{4} = 0.058$ sec. The 95% 2σ ranking reliability interval for runtime differences is ± 0.116 sec. That means runtimes must be minimal 0.12 sec apart for the ranking to be reliable.

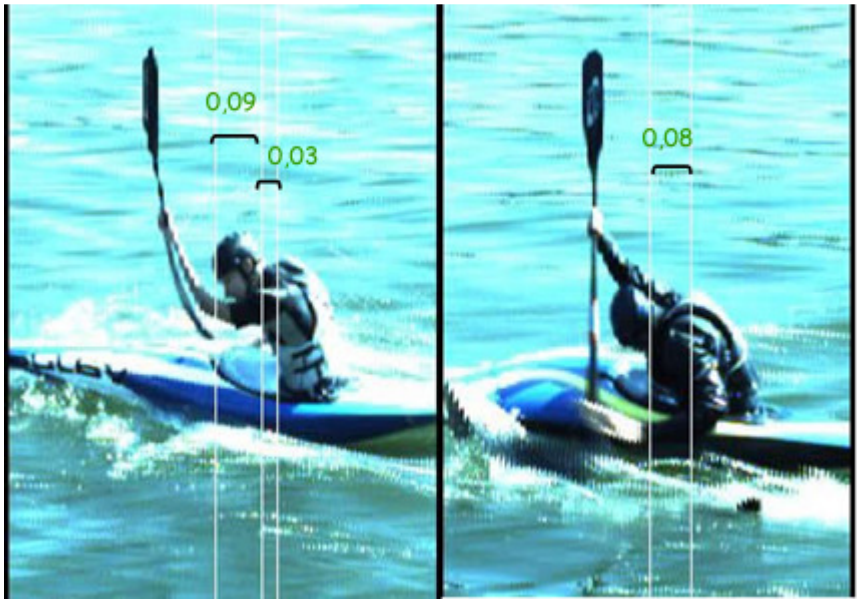
Dual beams are more accurate than single beams, but still not good enough for the required accuracy according to the slalom rules.

A problem with dual beams is that it is more difficult to get them aligned. They are more sensitive for misalignment due to a rap with the paddle. In some cases dual beams failed to register a finish. There was a bigger chance this to happen with participants bending forward.

7. Timing camera measurements

Timing camera measurements can improve the runtime accuracy to the level required by the slalom rules. But timing camera measurements have their intricacies too. The rules state that the crossing of the body of the start or finish line determines the start respectively finish moment. But have a look to the next timing photographs. The participants are bending forward during finishing.

There is a time span of 0.03 to 0.08 sec. between the chest and belly passing the finish line. Which line should be taken as the finish moment ?



And look at the photograph on the right. If the finish line is to be put on the chest, should it be put on the buoyancy jacket, or the estimated chest position? And if the finish line is to be put on the belly, then there is an arm in front.

From the timing photographs it is clear that the slalom rules are not precise enough in defining which part of the body crossing the start of finish line determines the start and finish moment.

Should bending forward be accepted or ignored in determining the finish moment? Does putting the finish moment on the back of the athlete provide better accuracy? Or would a mark on the side of the boat provide a better criterion for determining the start or finish moment ?

Without more precise specification what counts as the start respectively finish moment, it is to the discretionary judgment of the time keeper which line to select as the start and finish moment. This lack of precision may introduce an unreliability into the timing camera measurements of up to one tenth of a second.

Where timing cameras can provide the required accuracy from the rules, they have a drawback in timing operations. That is, it takes a few seconds before the finish time can be displayed. Where photobeams provide the finish time instantaneously. Other sports solve this by providing an unofficial instantaneous result from photobeams, corrected a few seconds later by the official timing camera result.

8. Conclusion

1. From a comparison of photobeam measured runtimes against timing camera measured runtimes, we can conclude that photobeam measurements do not attain the runtime accuracy that the slalom rules require.

2. The rankings on top slalom events that are measured with photobeams may not be reliable enough.

3. Timing cameras can provide the required accuracy.

4. The slalom rules need a more precise definition of start and finish moment to be applicable for measuring with timing cameras.

Timingteam

Timingteam provided Sports timing services in the Netherlands with a specialization in canoe/kayak races.