Use of Infrared Imaging for Track & Field

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ABSTRACT

At indoor track meets the shot put and weight are usually thrown onto carpet, wood, polyurethane, or concrete surfaces with little or no mark left to enable a precise measurement of the length of the throw. In the past the marking of the landing spot of the throw has been accomplished by the official's eye. We have introduced the use of an infrared camera (FLIR E2) to locate the heat of the impact of these implements. Depending on the surface type and factors of the throw, the landing surface is heated by the impact of the shot or weight approximately 3 degrees C, and the size of the spot persists about 2 minutes and completely disappears in about 5 minutes. The rapid disappearance of the spot eliminates confusion between two successive throws that may land in close proximity. We have measured a large number of throws using both the traditional eye method and the infrared method, and we have shown that there is a significant error from the eye method of marking. Infrared marking of the impact spot has resulted in a more precise and objective form of officiating while not requiring any additional time.

Keywords: Infrared, track & field, shot put, weight throw.

INTRODUCTION

Track & Field competition during the winter months is held indoors with running, jumping, and throwing. Of the usual outdoor throwing events only the shot put is thrown because of space limitations; the discus, hammer, and javelin would be too difficult to contain safely. The weight, 35 pounds for men and 20 pounds for women, is added for indoors. The shot, Figure 1, and the weight, Figure 2, are thrown about 20 m into a 40 degree angle sector for college throwers, usually onto a synthetic grass surface or a polyurethane surface. The distance of the throw is measured and rounded down to the lower centimeter. It is not uncommon for the winner to be decided by a few centimeters or less. Therefore, determining the exact landing spot of the implement is important.

***Figure 1**. Indoor shot put*

***Figure 2**. Weight.*

In the past, officials marking shot and weight events have had to visualize the landing spot from different distances and angles in relationship to the direction of the throw and then run to the memorized spot to mark it. We have introduced a new technique to allow a more precise method of marking utilizing infrared imaging to locate the true landing spot.

FINDING THE LANDING SPOT

Kinetic energy of a thrown implement is partially converted to thermal energy when the implement (shot or weight) lands on the floor surface. Some of this thermal energy or heat is retained on the floor surface and some remains with the implement. The following discussion is only about the thermal energy or heat on the floor surface.

All objects emit electromagnetic energy at temperatures above absolute zero. Some of the electromagnetic energy is in the infrared spectral band. The amount of infrared energy emitted by an object increases as temperature of the object increases. The far infrared spectrum of 7.5 to 13 microns wavelength was used for this study. A model E2 hand held thermal infrared camera manufactured by FLIR Systems AB, shown in Figure 3, was used to locate and display the infrared image where an implement landed.

Figure 3. *FLIR ThermaCAM E2 infrared camera with LCD (Liquid Crystal Display) screen.*

The E2 is a battery powered, self-contained instrument with a 6.3 cm LCD (Liquid Crystal Display) screen for viewing thermal images. The display temperature scale can be adjusted with various palette colors; the rainbow palette was selected with the camera assigning arbitrary colors to the various temperatures measured. The scale can be adjusted to give the desired temperature range, and the manual adjustment mode was selected. The scale was set to span a 4° Celsius range. The emissivity was set to 1.00 and the ambient temperature was set to the floor surface temperature. The image display is shown in real time similar to a video camera; there is no delay to view the image.

Figure 4 shows a typical image of a shot put. Since the indoor shot put is a flexible plastic shell filled with multiple lead pellets, and since this implement is easily deformed, the landing spot image is usually oval rather than round with the long axis of the oval in the direction of the throw.

Figure 5 shows a typical weight thermal image with the partial triangle of the image of the handle and connector. It has been very useful to be able to distinguish the landing spot of the handle from the ball since only the ball counts.

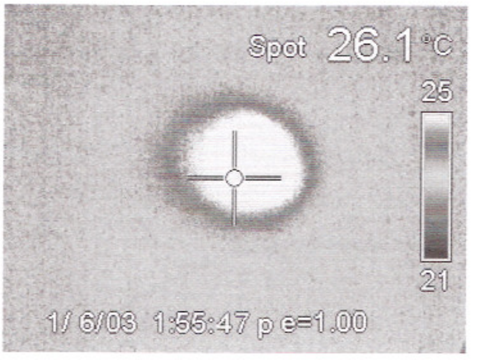

Figure 4. *Shot thermal image put from right to left.*

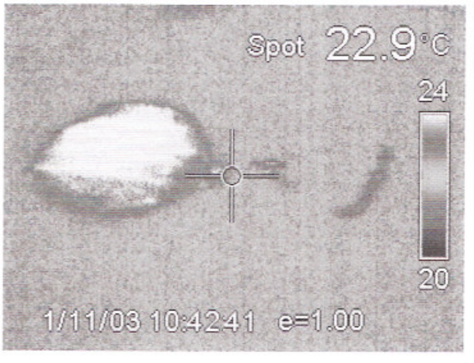

Figure 5. *Thermal image of a weight thrown from right to left. The partial triangle image represents the impact of the weight handle.*

Figure 6 shows two shot put spots with the small image being from a previous throw. There is no mistaking the current throw from the earlier throw, which was a concern of the coaches in our initial use of the infrared camera.

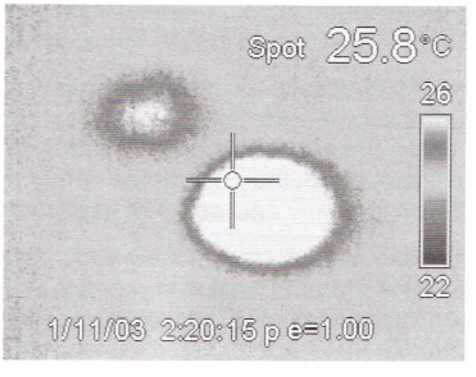

Figure 6. *A thermal image of two shot puts. The large image represents the landing spot of the most recent shot put. The upper left image was thrown two puts before.*

Prior to an actual track meet, a shot was put and the E2 infrared camera attached to a tripod was set up quickly to record images of the landing spot. The infrared images were stored within the camera memory at regular intervals. The size and the temperature of the landing spot were measured and plotted versus time, Figure 7, to show the duration of the heat image. There was no measurable increase in the size of the heat image that might have resulted from conducted heat on the carpeted surface. The size of the spot was constant for the first two minutes after which the size decreased.

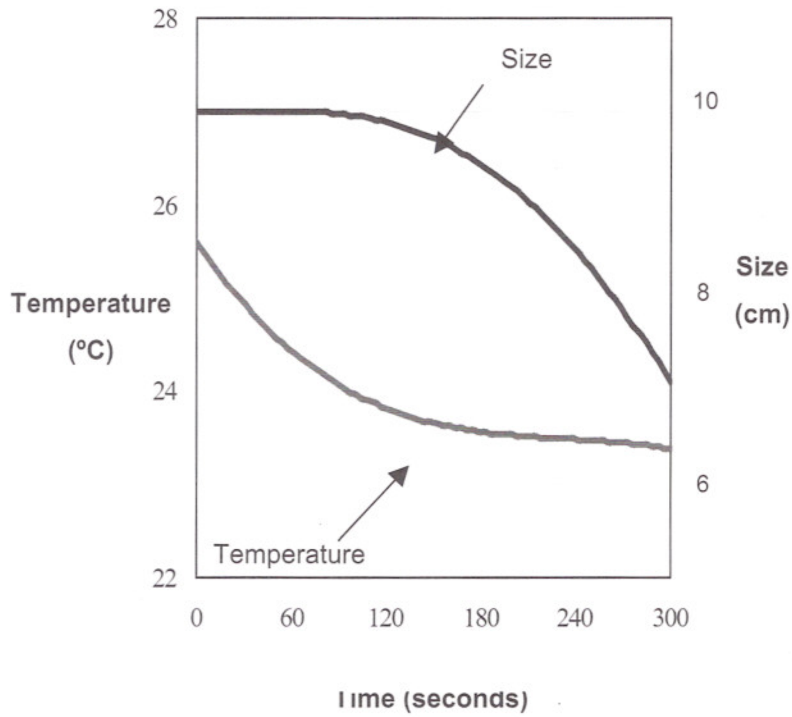

Figure 7. *Graph of diameter (size (cm)) and temperature (°C) of a shot impact spot over time. The diameter of the spot was constant for the first two minutes after which the size decreased for approximately three minutes. The temperature of the spot decreased about two degrees in the first two minutes at which time the temperature approached ambient temperature.*

Since only a few seconds are required to locate the landing spot, the two-minute constant size is more than necessary. The landing spot temperature decreased about two degrees in the first two minutes after which time the temperature approached ambient temperature. It is this loss of temperature that results in the landing spot to self erase itself, which makes this technique so useful.

The E2 infrared camera can store fifty images to its internal memory, and these images can be downloaded to a computer. Figure 2 shows a shot image put from right to left. An outer darker ring surrounds a hotter white central core. Based on experiments with a shot covered with chalk before being put, the edge of the chalk mark coincided with the edge of the darker ring. The crosshairs on the stored images represent the center of the picture only and were not used for marking the nearest edge.

Measurements between visual marking and infrared imaging allow marking errors of each throw to be compared. Summary statistics (Tables 1 and 2) were computed to illustrate the inefficiency of visual marking compared to marking with infrared imaging for four indoor events: the men's and women's shot put and the men's and women's weight, held at the United States Air Force Academy Indoor Field House in Colorado Springs, Colorado, on January 11, 2003. We marked 112 shot puts and 77 weight throws for the comparisons.

The locations of the nearest edge for the shot and weight were marked conventionally by best visual estimate. All throws were marked uniformly and from the same side of the sector during all four events. The location of the landing spot was visualized and a metal pointer was placed on the floor surface to indicate the mark before infrared imaging occurred. Then the true location of the nearest edge was shown on the E2 camera display with the heat spot clearly visible. A second wooden pointer was used to locate the nearest edge of the infrared heat spot on the landing surface. The difference between the visual and the infrared marks was measured with a ruler to the nearest half-centimeter and recorded as plus or minus. A negative sign indicated the visual mark was less than the true location and a positive sign indicated a mark greater than the true location. A positive difference would have been an error in favor of the athlete (adding distance to a throw). Statistical summaries by event of the mean absolute differences and frequencies are shown in Tables 1 and 2.

Event	N	**Greatest under-estimate**	**Greatest over-estimate**	**Absolute Mean**	**Standard Deviation**	**Standard Error**
Men's shot put	58	-8.0 cm	10.0 cm	1.7 cm	1.9	0.2
Men's weight	33	-8.0 cm	15.0 cm	3.7 cm	3.5	0.5
Women's shot put	54	-6.5 cm	16.0 cm	2.1 cm	2.0	0.3
Women's weight	44	-3.5 cm	9.5 cm	4.9 cm	3.5	0.6

Table 1. Summary statistics of errors measured between visually marked implement landing spot compared with infrared image of implement landing spot. Mean was calculated as an absolute difference between visually marked spot and true spot shown with infrared imaging. All visual implement landed spots were made by Daryl E. Mergen from the same side of the sector during all events.

Event	**Visual marks with an under-estimation**	**Visual mark agree with infrared image**	**Visual marks with an over-estimation**	**Visual marks 2 cm or less of true mark**	**Visual marks greater than 2 cm error**
Men's shot put	14%	29%	57%	74%	26%
Men's weight	23%	7%	70%	49%	51%
Women's shot put	20%	16%	64%	70%	30%
Women's weight	21%	9%	70%	24%	76%

Table 2. Error size and frequency of visual marks compared with true marks shown with infrared imaging.

The absolute mean error by event (Table 1) shows that visually marking of shot puts is more accurate on average compared to marking weights throws. The average error was 2 cm or less for both men and women shot put events. The average error for women's weight event was about 5 cm and 4 cm for the men's event. Standard deviations and Standard errors also illustrate the variability in error for the weight event was greater compared to the shot put. The distance and angle an official is from a landing spot may influence accuracy of visual marks.

When frequency of individual errors are summarized the error between visual marking and infrared imaging becomes much more apparent and could have significant effects on the results of the specific field event. Fourteen to twenty percent of the visual marks resulted in underestimations of the true mark and 57-64% of the marks were overestimates for the men and women's shot respectively. Twenty nine percent of the marks made during the men's shot and 16% of the marks during the women's shot event were the same as the true mark displayed with the infrared camera. Seventy-four percent of the visual marks were off by about 2.5 cm or less for the men's shot while the other 26% of the throws were off by a distance greater than 2.5 cm. Results of the women's shot show 70% of the visual marks were off 2.5 cm or less and 30% were in error of more than 2.5 cm. The greatest errors recorded included a 10 cm overestimate and an 8 cm underestimate for the men's shot. Women's shot greatest errors were slightly less than the men's (Table 1). The worst-case scenario for visually marking could have resulted in an 18 cm marked difference between two throws. For example athlete A was visually underestimated by 3 cm and athlete B was visually overestimated by 15 cm. Even though both throws were actually equal there was an 18 cm marking error. This difference could significantly impact event results if the marking errors were made on provisional qualification throws or throws where athlete placements within the event were within 18 cm.

Weight throw errors compared by frequency were even greater than shot put results. The visual mark of the weight was overestimated (favored the athlete) 70% of the time and underestimated 21-23% of the time and visually marked correctly only 7-9% of the time for the men and women events respectively. Fifty-one percent of the men's weight throws and 76% of the women's throws were marked in error of more than 2.5 cm. The greatest errors for both men and women's events resulted in about a 23 cm). Once again, the worst-case scenario could have resulted in equal throws being visually marked with a 23 cm difference. The use of the infrared camera eliminates all error in visual marking and improves the precision of each measured throw during indoor field events.

SUMMARY

We have shown that the use of an infrared camera allows the precise marking of a thrown implement compared with visual marking. It does not delay marking and may even expedite the process in the event that two officials disagree on the visual mark, which is not uncommon with that method. The infrared imaging also eliminates any questionable calls of throws that are near sector lines. The technique will work well on almost any uniform indoor surface such as carpet, polyurethane, wood, or concrete.

After introducing this technique at the Air Force Academy, the coaches running the NCAA Division I National Indoor Championships at the University of Arkansas invited us to mark the weight throw events. In the men's weight first and second places were decided by only 2 cm. We considered this invitation to be the ultimate complement in the first year of our use of this technique. The acceptance of this technique by coaches all over the country has exceeded our expectations.

REFERENCES

4. Planck, Max; "Ueber das Gesetz der Energieverteilung im Normalspectrum"; p553; *Annalen der Physik*; vol. 4; 1901

5. Urone, Paul Peter; p157; *College Physics*; Brooks/Cole Publishing Company; Pacific Grove, et al; 1998

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