NOTE

Measurement of Wheat Grain Thickness Using Profilometry

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The price of wheat in trade is affected by the percentage of screenings, which includes cracked, broken, shriveled, or small, whole grains. This is because, in milling, this material is removed from the sound wheat in the screen room and becomes incorporated into the lower value by-products. The conventional test for screenings is measurement of the percentage by mass of a sample that passes through a slotted screen of a designated width. However, this method is subject to errors arising from operator influence and variation in the dimensions of the slots due to manufacturing tolerances and wear. Consequently, there have been attempts to develop more objective methods for the estimation of screenings in wheat. For example, Lambe and Morris (2002) described a simple test for estimating the percentage of screenings in a grain sample from the diameter distribution measured using the Perten Single Kernel Characterization System 4100. However, a more popular approach to the objective determination of broken, damaged, or foreign grains involved the use of digital image analysis (Sapirstein et al 1987; Chen et al 1989; Thomson and Pomeranz 1991; Luo et al 1999; Armstrong et al 2003; Paliwal et al 2003; van Dalen 2004; Pearson and Brabec 2006)

Most of these imaging studies, including Sapirstein et al (1987), who analyzed digitized silhouettes of grains, and Pearson and Brabec (2006), who captured images of grains in an SKCS weigher bucket, have involved single cameras viewing grains on a flat surface. Typically, only the two largest dimensions, length and width, can be measured by such systems (Pearson and Brabec 2006). However thickness, rather than length or width, is the critical measurement for the estimation of screenings because if 1) a wheat grain is well modeled by an ellipsoid as proposed by Mabille and Abecassis (2003), even allowing for a crease; 2) the screen has been shaken enough times; 3) the screen slots are longer than the longest grain (which is typically the case); and 4) the screen slots are all of a uniform width, then it is clear that the grain will fall through the screen if, and only if, its minimum dimension (thickness) is smaller than the slot width.

Two reports (Chen et al 1989; Thomson and Pomeranz 1991) used laser range finding to enable estimation of thickness; a third (Armstrong et al 2003) describes an indented tray that allows some grains to be held edge-on so that the thickness can be estimated from images. Kim et al 1997 used a camera positioned above individual rice grains and two mirrors to obtain top, side, and front (end-on) views of each kernel. Both Paige et al (1991) and Ni et al (1998) used a camera above individual grains and a single mirror to obtain top and side (but not front) views of each grain. Paige et al (1991) investigated rice grains, while Ni et al (1998) investigated maize grains.

The engineering of any method to deliver a reliable low-cost solution will require significant investment, so it is important to start with the simplest method compatible with current industry requirements. Optical methods for estimating dimensions have two powerful generic advantages. First, they lead readily to digital data. Second, they allow direct comparison of the object to be measured with a physical standard in the same view or image, with the result that possible errors can be estimated from geometrical relationships. This report describes the principles of a simple optical method that seems to meet the requirements for screenings determinations (thickness measurement by optical profilometry) and investigates the achievable precision and reproducibility that this method can readily deliver for whole and broken grains of wheat.

MATERIALS AND METHODS

Profilometry

The profilometer measures the thickness of an object, in this case a whole or broken wheat grain, by measuring its optical profile against a reference length standard. It comprises a PC computer, an OEM Firewire industrial monochrome digital camera (model A102F, Basler Vision Systems, Ahrensburg, Germany) with a macro telescope, a V-block grain holder made of white semitransparent plastic, and a parallel light source to provide an accurate profile of objects placed in the V-groove. Illumination is provided by a red light-emitting diode (LED) and convex lens positioned behind the V-block supporting the grain, as shown in Fig. 1. The LED light source is placed close to the focus of the convex lens to produce an approximately parallel (collimated) beam of light that illuminates the wheat grain situated in the V-groove. The telescope is then focused approximately midway along the V-groove to record the shadow of the grain in the collimated beam of illumination,

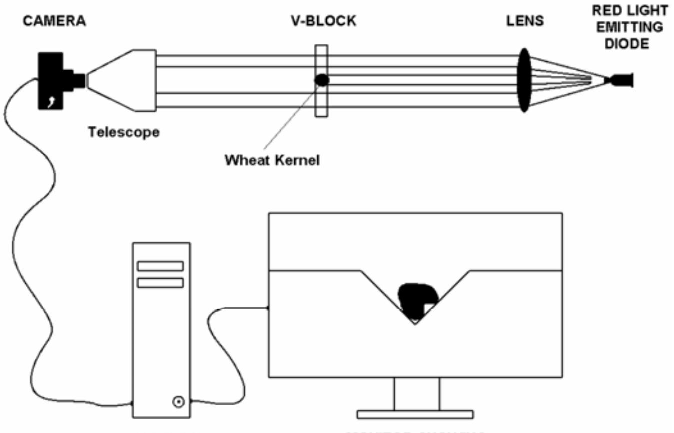

Fig. 1. Experimental profilometer for grain profile measurements.

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along with the shadow of an aspect of the apparatus constituting a physical standard of length in the same plane, such as the width of the V-block in Fig. 1. The system shows images of a region ≈10 mm × 7.5 mm in the centre plane of the V-block, yielding a pixel size of ≈0.02 mm in the image of the grain shadow.

Grain Samples

A total of 280 grains were hand-picked from a sample of Australian wheat to represent a range of sizes. These included 28 broken grains.

Grain Thickness Measurements

Micrometer. Thickness of each of the 280 grains was measured with a micrometer (model 206-101, Mitutoyo Corporation, Kawasaki, Japan). Two thickness measurements were made on each grain, in which each of the 280 grains was measured once and then the whole set was remeasured. Where possible, the thickness was measured across the crease. It was difficult to measure the thickness of broken grains, and the micrometer tended to compress all the grains slightly during measurement. A micrometer was used in preference to a pair of vernier calipers to measure a thickness more comparable with that measured by the profilometer for that percentage of grains that have some curvature in the plane of the crease. The micrometer was oriented with its jaws horizontal, and the grains were placed crease down on the lower jaw. The aperture of the jaws was, in all cases, greater than the length of the grain. Apart from the effects of grain compression, this method measures a distance corresponding as closely as possible to the distance across its optical profile, whether or not the grain has curvature in the plane of its crease.

Profilometer. A total of 60 grains (including 10 broken grains) were randomly chosen from those whose replicate micrometer measurements were within 0.020 mm of each other (i.e., those which were highly repeatable and thus likely to be most accurate). The 60 grains were randomly reordered and measurements were made in this random order. For each of the 60 grains, a profile image was recorded from each end of the grain, producing two replicate profiles for each grain. Each grain was manually mounted on the V-block and aligned axially by eye with the V-groove axis each time it was measured. Where possible (although this was sometimes difficult for the broken grains), the grain was placed with the crease facing one of the sides of the V-groove in the expectation that nonbroken grains would tend to sit in a more "repeatable" position when placed against a flat surface. The grain thickness was estimated using the minimum transverse diameter, widely used in image analysis and often called the Feret diameter. The minimum transverse diameter attempts to do in software what a micrometer does with a real grain. Notionally, for a fixed angle, a pair of parallel lines is placed so that the two lines are just touching opposite sides of the grain, and the perpendicular distance between them is measured. This is illustrated in Fig. 2, which shows the profile of a grain with the minimum (thickness) and maximum (width) transverse diameters highlighted. CSIRO proprietary software was used to calculate good digital approximations to these diameters. After using a sophisticated algorithm that finds the boundary pixels of a grain, the maximum of the distances from each boundary pixel to every other boundary pixel was computed. This gave the transverse diameter corresponding to each boundary pixel. The minimum and maximum of these transverse diameters was then found.

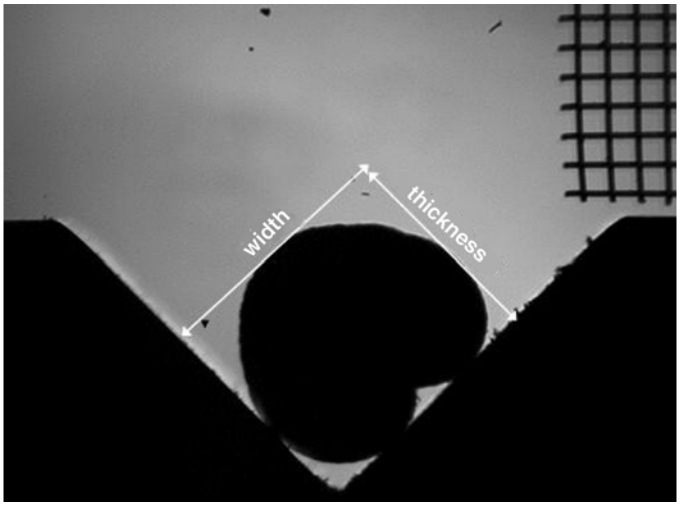

Fig. 2. Shadow profile of one grain with minimum (thickness) and maximum (width) transverse diameters highlighted. Mesh in top right-hand corner was used to calibrate measurements.

RESULTS AND DISCUSSION

Repeatability of Micrometer and Profilometer Measurements

The standard deviation of differences between the replicate micrometer measurements was similar for both whole grains (0.063 mm) and broken grains (0.073 mm). The standard deviation of differences for the profilometer was lower than that for the micrometer for the whole grains (0.036 mm), but higher than that for the micrometer for the broken grains (0.113 mm).

Table I summarizes the differences between the replicate measurements for whole and broken grains, for both micrometer and profilometer measurements. Differences between numbers were small (<0.02 mm), medium (0.02–0.1 mm), and large (>0.1 mm). It is clear that, for broken grains, profilometry measurements showed fewer small differences than micrometer measurements, while profilometry measurements showed more large differences

TABLE I
Summary of Differences Between Replicate Micrometer and Replicate Profilometer Measurements for Whole and Broken Grains

	Difference Range		
Grain Type	**<0.02 mm**	**0.02–0.1 mm**	**>0.1 mm**
Whole micrometer	76%	12%	12%
Whole profilometer	42%	52%	6%
Broken micrometer	71%	15%	14%
Broken profilometer	30%	40%	30%

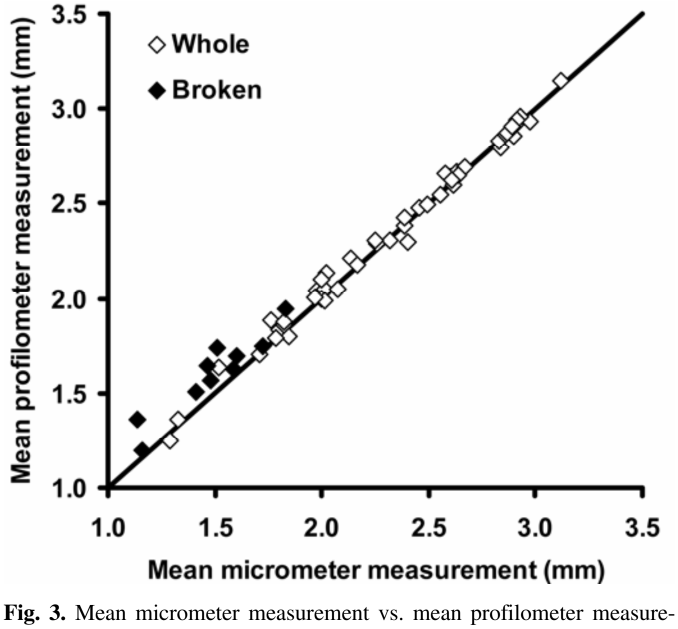

Fig. 3. Mean micrometer measurement vs. mean profilometer measurement for 60 grains.

than micrometer measurements. It may be inferred that a viable profilometry system would need to include an appropriate shape measure to exclude broken grains or other unusually shaped grains which cause similar problems. Visual inspection of profiles with unusual shapes suggests that this will not be difficult to do.

Meanwhile, Table I shows that a significant majority (76% for whole and 71% for broken grains) of the micrometer measurements (214 grains in total) had small differences (<0.02 mm). This gives confidence that the mean micrometer measurements of these 214 grains provided a good standard for assessing the performance of the profilometry measurements.

Mean Micrometer and Mean Profilometer Measurements

Figure 3 presents a plot of the 60 mean profilometer measurements (*y*-axis) against the corresponding mean micrometer measurements (*x*-axis). The mean micrometer measurement and the corresponding mean profilometer measurement differ by <0.2 mm for all but one of the whole grains. In many cases, the difference was much less than this.

The profilometer measurements shown in Fig. 3 are, on average, slightly larger than micrometer measurements. The mean and root mean square error of differences between micrometer and profilometer measurements were 0.02 and 0.05 mm, respectively, for the whole grains, and 0.11 and 0.13 mm, respectively, for the broken grains. This is an excellent level of agreement for whole grains.

The results presented above demonstrate the principle of a profilometry method for the estimation of grain thickness. However, further work will be required to design an automated system for presentation of individual grains to the profilometer. Possible solutions could include a moving belt on which grains would pass the optical system or a singulator such as that used in the SKCS 4100. Since this aspect of the method has not yet been addressed, the work presented here was based on a manual procedure. Because manual positioning of the grains was difficult, and hence time-consuming, only 60 grains were used for this exploratory study.

CONCLUSIONS

Profilometry was repeatable and in good agreement with micrometer measurements for whole grains, provided that the grain is carefully positioned, with its crease against a flat surface, where possible. It may therefore be concluded that optical profilometry using very low-cost components offers a suitable basis for a low-cost technology for monitoring screenings with significant potential for delivering digital information traceable to a primary physical standard (length) in an automated manner. The physical standard can be any convenient dimension of the supporting apparatus, or a standard object of known length, presented in the plane of measurement, for the purpose of improved accuracy, portability, or transferability.

Future work will require development of a suitable system for handling the grains and presenting them for optical assessment as well as a test for unusually shaped (mostly broken) grains that are prone to erroneous estimation of thickness by profilometry and would probably be automatically classified as screenings.

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