Pixel Calibration Techniques

Donald G. Bailey

Image Analysis Unit
Massey University, Palmerston North
E-mail: D.G.Bailey@massey.ac.nz

Abstract
Any image analysis application that involves making real world measurements requires the image processing system to be calibrated. In particular, the aspect ratio and area of the pixels must be determined so that pixel measurements can be translated into physical measurements by scaling. Two approaches to calibration are compared, looking at the following aspects: sensitivity to threshold selection; sensitivity to calibration object size; sensitivity to focus; and sensitivity to noise. Preprocessing techniques are considered for reducing the sensitivity to these various factors. It is shown that calibration techniques based on area and moments are more precise than those based on length.

1. Introduction
Image analysis is the branch of image processing concerned with extracting numerical data from images. The type of data extracted includes: area, length, position, count, intensity (or density), texture, movement (or the change of any of these features with time). If the measurements made include length, area, or position, and the measurements are required in physical, real world units, rather than in pixels, the image analysis system needs to be calibrated.

Calibration involves determining the correspondence between pixel units and physical units. This allows any measurements made in pixel units to be converted to physical units by scaling. For calibration, two out of the following four parameters need to be measured: pixel height, \( h \); pixel width, \( w \); the aspect ratio \( ar = h/w \); and pixel area, \( a = hw \).

On systems where the aspect ratio is approximately 1:1, often only a single measurement is made. However, even on such systems, more accurate results may be obtained by measuring the aspect ratio because it may vary from 1.0 by several percent. This is because the aspect ratio is not determined solely by the image capture card, but also by the camera (the physical layout of the sensing elements on the sensor, and the rate at which the elements are read out).

1.1 Calibration procedure
A circular object of known diameter was chosen for calibration because its size is independent of object orientation. Since the calibration object is contrived, there is no problem obtaining a good contrast image (see figure 1). An image of the object is captured, then thresholded, and features of the resulting image measured. Two methods of pixel calibration will be compared in this paper: length based measurements, and area based measurements.

Measurements based on length are the most direct. Let the (known) diameter of the calibration object be \( D \). The vertical extent or height of the object, \( H \), and the horizontal extent, \( W \), are measured. The calibration parameters can then be calculated as:

\[ h = \frac{D}{H} \quad w = \frac{D}{W} \]
\[ ar = \frac{h}{w} = \frac{W}{H} \quad a = hw = \frac{D^2}{HW} \]
Area based measurements use the area of the calibration object in pixels, $A$, and the second order central moments, $\mu_{20}$ and $\mu_{02}$. The moments correspond to the variance of the object in the horizontal and vertical directions respectively and therefore serve as a measure of the object's extent. The calibration parameters can then be calculated as:

$$ar = \sqrt{\frac{\mu_{20}}{\mu_{02}}}$$  
$$a = \frac{\pi D^2}{4A}$$  
$$h = \sqrt{a,ar}$$  
$$w = \sqrt{\frac{a}{ar}}$$

2. Sensitivity to threshold selection

Even when the image is perfectly in focus, the pixels around the edge of the object have values in between those of the object and those of the background. The actual value of each pixel depends on the proportion of the pixel area covered by the object and background. These pixels must be classified as either object or background before any calibration measurements are made. Thresholding is the most common method of performing this classification. Although any threshold level between the levels of the object and background could be used, as the threshold changes, the area of the object, and hence the calibration results will be affected. Figures 2 to 4 show the effect of changing the threshold on the measured aspect ratio, pixel width and pixel area.

Both sets of measurements follow a similar form, although those based on length are more discrete, with steps at the intensities at which the object changes size. These pixel-based effects limit the accuracy of length based calibrations. The area based measure of the aspect ratio is virtually independent of the threshold level (within 0.1%). The other measurements show the expected decrease with increasing threshold, as the size of the object in pixels increases. With correct selection of threshold, area based measurements are more accurate.

The logical value for the threshold level is exactly half way between the pixel values of the object and the background. This classifies pixels with more than 50% of their area covered by the object as belonging to the object. In the examples shown, this corresponds to a threshold level of 125.

3. Sensitivity to object size

To test sensitivity to the size of the calibration object, a series of different sized calibration circles was measured at the same camera setting. The size of the steps in the length based measurements increased considerably as the size of the object reduced. The accuracy of the area based measurements also deteriorated as the size of the calibration object was reduced (figures 5 and 6). This is shown by the increased variation in aspect ratio as a function of the threshold level, and the increased slope of the measured pixel width vs threshold level. This increase in slope indicates an increased sensitivity to the threshold level as the calibration object becomes smaller. For best results, the calibration object should be as large as possible while still fitting within the field of view of the camera.
Figure 2: Sensitivity of the measured aspect ratio to the threshold level.

Figure 3: Sensitivity of the pixel width measurement to the threshold level.

Figure 4: Sensitivity of the pixel area measurement to the threshold level.
4. Sensitivity to focus

A series of images of the same 50 mm calibration object was taken, adjusting the focus to successively blur the images. The blur point spread function (PSF) was estimated using a Wiener filter [1]:

$$PSF = \text{FFT}^{-1}\left(\frac{BA^*}{AA^* + N}\right)$$

where $A$ and $B$ are the FFTs of the original and blurred images respectively, $*$ represents complex conjugation, and $N$ is a constant introduced to prevent division by 0. The PSF was approximately circular in shape. This was thresholded at one quarter of the maximum level, and the diameter calculated from the area.

The effect of focus on the calibration measurements was observed by looking at how the sensitivity to the threshold level changed with blur. The aspect ratio measurement was reasonably constant, although tended to oscillate quite wildly with threshold when length based measurements were used. As the images become more blurred, the pixel width measurement changes more rapidly with threshold (the slope of the line is plotted against blur in figure 7). This makes selection of the correct threshold more difficult. However, as long as changing the
focus does not affect the magnification, and the correct threshold is used, precise focus is not critical.

\[
\begin{array}{ccccccc}
-0.30 & -0.25 & -0.20 & -0.15 & -0.10 & -0.05 & 0.00 \\
\hline
0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 \\
\end{array}
\]

**Figure 7:** Sensitivity of the pixel width to threshold level as the image is blurred.

5. Sensitivity to noise

Since the calibration object is artificial, there should be little difficulty obtaining good contrast, low noise images. However, there will always be a certain level of noise present and this has two effects. First, it spreads the peaks of the histograms, making it difficult to estimate the object and background pixel values and therefore the correct threshold level. Second, it affects pixel values in the critical edge region causing edge pixels to be misclassified as object or background. Length based calibrations are most affected by noise since they detect the maximum extent of the calibration object. Noise will make the object appear larger, decreasing the measured value for pixel width and area. Noise does not affect area based measurements significantly, as shown in figure 8.

\[
\begin{array}{ccccccc}
19500 & 19450 & 19400 & 19350 & 19300 & 19250 & 19200 \\
\hline
0 & 5 & 10 & 15 & 20 & 25 & 30 \\
\end{array}
\]

**Figure 8:** Effect of noise on calibration results.

6. Preprocessing to reduce sensitivity

Area based measurements are insensitive to noise, so unless it is severe, preprocessing is not required to reduce the noise. The most significant sensitivity is to threshold level. This sensitivity may be reduced by enhancing the edges around the object. Two enhancement methods are considered - linear enhancement with the following weights:

\[
\begin{array}{ccc}
-1 & -1 & -1 \\
1/4 & -1 & 12 & -1 \\
-1 & -1 & -1 \\
\end{array}
\]

and a rank-based edge enhancement [2,3]. The latter method effectively classifies the edge pixels as belonging to the object or background depending on which is closer. As shown in
figure 9, this significantly reduces the need for careful threshold selection.

7. Conclusions

Area based calibration measurements are more accurate than those based on length. The results are less sensitive to threshold level, and noise. The reason for this difference is that lengths are measured point to point, and are therefore differential by nature, making them more sensitive to noise and limited by pixel resolution. Measurements using area and moments are integral by nature and therefore less sensitive to noise. Since they use information from the complete object, they are also less affected by the discrete nature of the pixels.

7.1 Recommended calibration procedure

A circular object (eg a lens cap) should be used for performing the calibration. It should be as large as possible within the field of view of the camera. The image processing steps are:

- Capture an image of the object.
- Enhance the edges around the object using a rank based edge enhancement filter.
- Obtain the intensity histogram, $H$, of the result (for calculating the threshold).
- Calculate the threshold intensity as follows:

\[
\text{let } \text{mean} = \frac{\sum_{i=0}^{255} iH(i)}{\sum_{i=0}^{255} H(i)}
\]

\[
\text{then } \text{threshold} = \frac{1}{2} \left( \frac{\text{mean} iH(i)}{\sum_{i=0}^{\text{mean}} H(i) + \sum_{i=\text{mean}}^{255} iH(i)} \right) \left( \sum_{i=0}^{255} H(i) \right)
\]

- Threshold image and select the calibration object within the image.
- Measure the area and second moments of area.
- Calculate the calibration parameters.

References:

