Landmark and other methods for assessing plant part shape

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1 Introduction

The appearance of parts of plants is important in horticultural science. Plant breeders use it in assessing the distinctness, uniformity and stability of cultivars, which are important criteria in certification of new cultivars. Appearance of plant parts consists mainly of colour, size and shape, and it is shape which shows the most complex and important variation. Image analysis has a clear role in ensuring objective and reproducible assessment of shape. A common interest is to develop some method of generating an average shape for each cultivar.

For many plant parts, which are convex and laterally symmetric it is not difficult to describe the shape. Examples are many types of leaves, and carrot roots (although these may show finer detail in the crown). In these cases, shape is described by the width as a function of distance from one end to the other. If the width is recorded at a number of distances, standard statistical methods may be used with these (Horgan *et al.*, 2001). For more complex parts, more general shape methods are needed.

Fig 1 shows an image of stipules sampled from a pea (*Pisum Sativum*) plant. These are not convex, and simple width functions cannot describe the variation in shape. It can also be seen that in addition to the overall global shape, their appearance presents some fine detail. Most of the stipules have a series of dentations around part of the outline. These are important characteristics, and their number, shape and depth may vary between cultivars. A full description of shape needs to account for these local features.

2 Image analysis

Image analysis is sometimes used routinely in plant image assessment (see, for example, van der Heijden and van den Berg, 1997). Although it would be preferable to obtain images in the field, there are many practical difficulties involved, and parts are usually harvested and images obtained in a laboratory setting. This allows a uniform black background, and plant parts to be placed so as not to overlap, thereby simplifying analysis. Fig 1 shows a typical example. Standard image analysis allows features such as size, overall length, width and colour to be obtained. Fig 2 shows the image of Fig 1 annotated to show the main measurements made on each stipule.

The usual way to describe shape is in terms of variation in the positions of a number of anatomical landmark points. It is not always clear what these should be. Only two are natural and easy to find on the stipule: the point where the stipule was attached to the petiole (i.e. the indentation on the outline) and the tip. Other landmark points are mathematical. The point furthest from the tip (which we will denote as L) is a natural choice. We can then add the points on the outline furthest from lines drawn from the base (indentation) to the tip and to L. These are all readily obtained from the images.

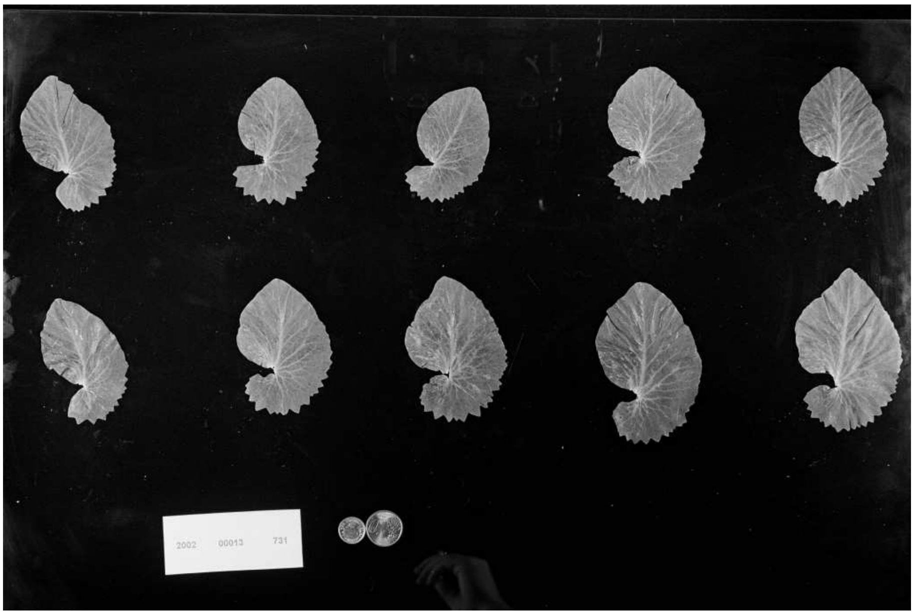

Figure 1: Image of pea stipules.

Dentations can be found as local maxima of the distance of points on the outline from the base or possibly from the centroid of the leaf or its outline. We also add a condition that the maximum distance exceeds that at nearby points by a certain amount. Dentations can then be counted, and an indication of their shape obtained from the local curvature.

3 Shape averaging

It is desirable to be able to display images denoting the mean shape for different cultivars. Two possibilities for doing this are

- To describe the shape in terms of a 'skeleton' based on the landmarks. The positions of the tip and the point L can be defined by the length of and angle between line segments from the base, and the remaining three landmarks defined relative to these.

- Generalised Procrustes analysis (GPA) is an established method for obtaining the average configuration of a set of landmarks.

GPA enjoys the advantage that it can be used with any number of landmarks and treats them all equally. However, it is more computationally demanding for large datasets, and needs to be recalculated when additional samples are obtained.

Having obtained a mean landmark configuration, it is then necessary to generate a reconstructed stipule from it. We have used quarter ellipses, i.e. points (x_1, y_1) and (x_2, y_2) are joined by

$$y = y_1 + (y_2 - y_1)\left(1 - \left(\frac{x - x_2}{x_2 - x_1}\right)^k\right)^{1/k}$$

for $x_1 \leq x \leq x_2$, where $k = 2$. Other values of k could be used, and this would indicate another aspect of shape not reflected in the landmark configurations. If this were important, it could be envisaged that k would be estimated from sample stipules, and averaged. A reconstructed mean stipule outline is shown in Fig 3.

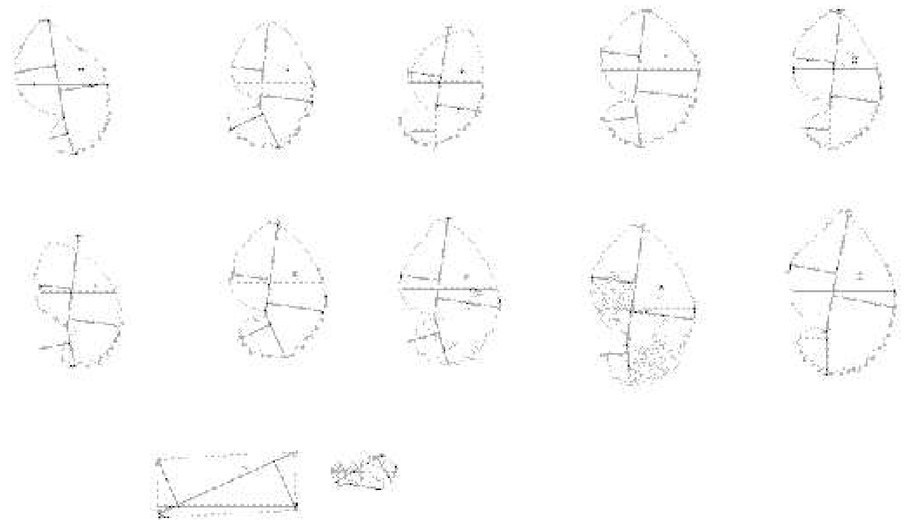

Figure 2: Stipule image annotated with measurements. Some slight misalignments are due to individual stipules being rotated to the vertical before measurement.

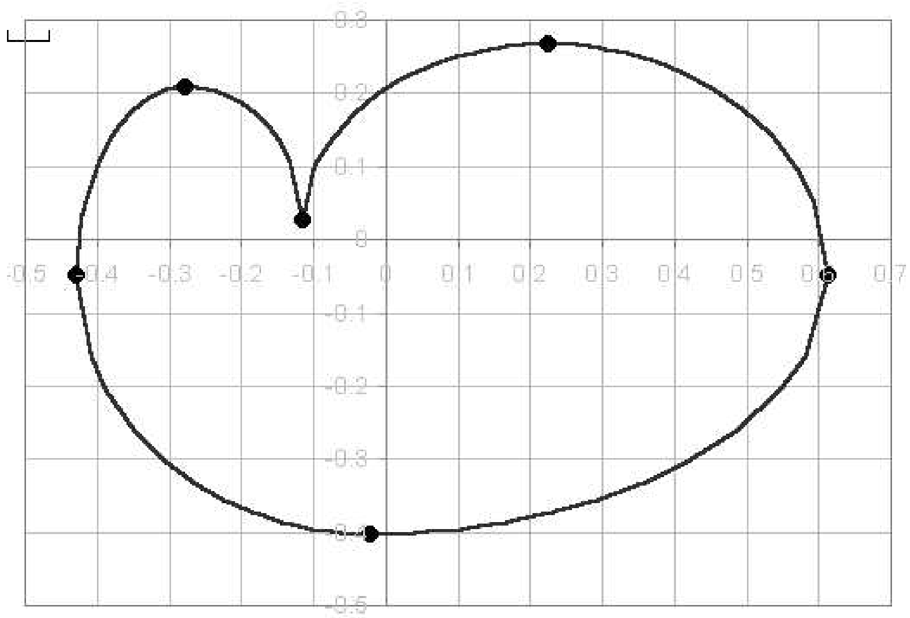

Figure 3: Reconstructed average outline obtained from stipules in Fig 1. Procrustes rotation was used. Mean landmark positions are also shown.

4 Conclusions

Methods of shape analysis have the potential to assess variation in the shape of plant parts, and to enable the reconstruction of mean shapes. Further work is needed to address several questions. These include the issue of how many landmarks and other features are needed for a satisfactory shape description, and how the local shape features such as dentations can be integrated with an assessment of overall shape variation. When datasets are large, we might also consider it more useful to investigate ways of finding a ‘typical’ representative plant part rather than attempting to reconstruct one from the means of shape features and/or landmark configurations.

References

Heijden, van der, G.W.A.M. and Berg, van den, R.G. (1997). Quantitative assessment of corolla shape variation in *Solanum* sect. *Petota* by computer image analysis. *Taxon*, **46**, 49-64.

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