Illumination Cone

Christopher Metcalfe
<c.e.metcalfe@sms.ed.ac.uk>

Introduction

It has been shown empirically that changes in images due to lighting and pose can be greater than changes in the actual object's identity. For many methods of object recognition, e.g. edge detection, changes in illumination can cause shadowing, which can mask or change certain features of an image. Belhumeur and Kriegman (1996) theorize that if the appearance of any two objects is never identical for any pose or lighting conditions, then – in theory – the objects can always be distinguished or recognised.
With an infinite number of possible lighting conditions, including an infinite number of sources, and an infinite number of poses possible, what is the set of n-pixel images of an object under all lighting conditions and pose? In other words is there a method of modelling and object which is not sensitive to illumination and pose?
Belhumeur and Kriegman (1996) propose a property of images called the illumination cone. This cone (a convex polyhedral cone in IR^n and with a dimension equal to the number of surface normals) can be used to generate and recognise images with novel illumination and pose conditions (Georghiades and Belhumeur; 2001) and can be created from as few as three carefully chosen training images.

Developing the illumination cone

(Full details of the derivation can be found in Belhumeur and Kriegman (1996), what follows is a brief discussion of the main assumptions and stages in the proof.)

The original concept of the illumination cone is based on two major assumptions:
1- The surface of objects have Lambertian reflectance functions.
2 – The object's surface is convex in shape.

Although these are very strong assumptions of objects and situations in which they are both entirely met would possibly be rather contrived, many studies () have shown that the illumination cone is a very robust property and can outperform many other recognition algorithms over a vast range of input data.

During the course of the mathematical proof for the illumination cone there are three major steps:

1 – The set of images L_0 is a convex cone in IR^n.
2 – The set of images $P_i(L_i)$ is a convex cone in IR^n.
3 – C is the set of all possible images of a convex Lambertian surface created by varying the strength and direction of an arbitrary number of light sources at infinity and that this set of images is convex cone in IR^n.
The set C is the illumination cone. Every object has its own illumination cone

(figure 1), the entirety of which is a set of images of the object under all possible lighting conditions, and each point on the cone is an image with a unique configuration of illumination conditions.

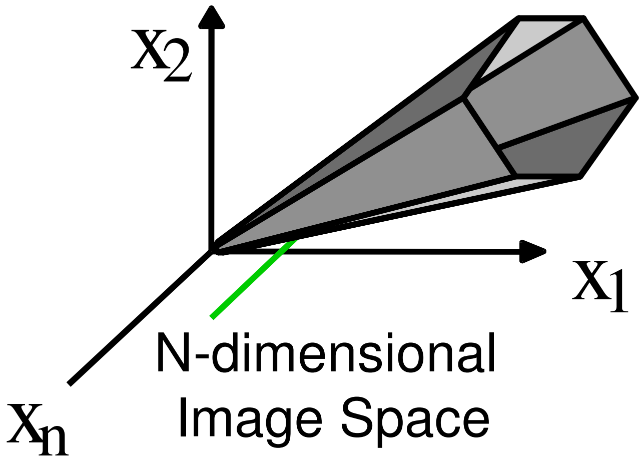

Figure 1 A graphical representation of the illumination cone as plotted on the image space.

Through further proof it is possible to conclude that
"The set of n-pixel images of any object seen under all possible lighting conditions is a convex cone in IR^n ."
and that this cone can be constructed from as few as 3 images.

Further application of the illumination cone

Belhumeur and Georghiades (2001) have used the illumination cone to further show that, using a small number of training images, the shape and albedo of an object can be reconstructed and that this reconstruction can serve as a model for recognition or generation of novel images in various illumination or poses. For construction of images in a fixed pose, an illumination cone is constructed from the teaching data, and from there an image can be generated at any position on the cone which is a superposition of the training material (Figure 2).

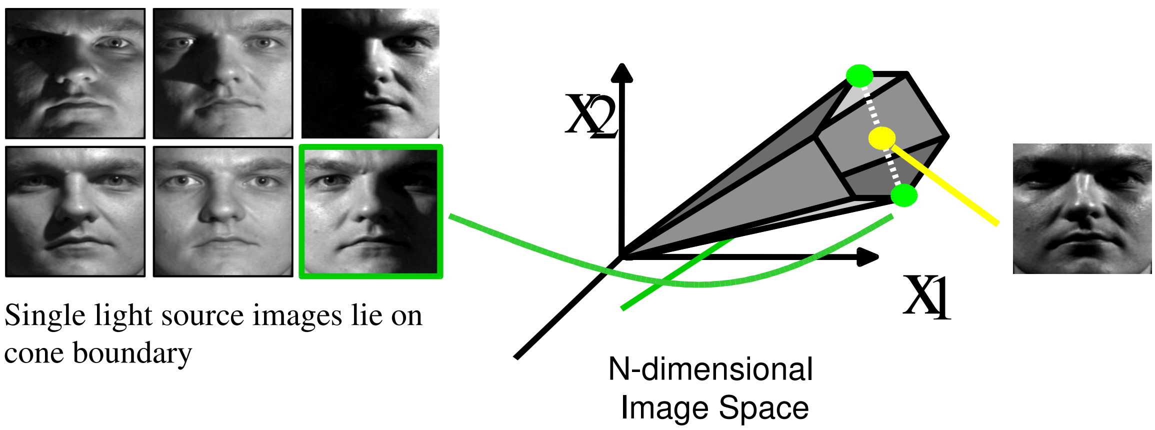

Figure 2 An example of the generation of novel data from an illumination curve

References

P. Belhumeur and D Kriegman (1996). What is the set of images of an object under all possible illumination conditions. *In Proc. of the IEEE Conf. On Computer Vision and Patten Recognition, 1996.*

http://www-cvr.ai.uiuc.edu/kriegman-grp/publication/papers/cvpr96b.ps.gz

A.S. Georghiades, P. Belhumeur and D. Kriegman (2001) From few to many: Illumination Cone Models For Face Recognition Under Variable Lighting And Pose. *In Proc. IEEE Trans. On Pattern Analysis And Machine Intelligence.*

http://www-cvr.ai.uiuc.edu/kriegman-grp/publication/papers/tpami01.pdf

Figure 1 and 2 taken from lecture notes by Jim Rehg at Georgia Institute for Technology Sept 15, 2003.

http://www.cc.gatech.edu/classes/AY2004/cs4495_fall/Materials/11Lambertian_CS4495_9-15-03.ppt