

Unsharpmask Your Pictures

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Unsharp mask (USM) is a powerful technique for enhancing astronomical images. Despite its misleading name, its visual effect is actually sharpening images. Just a few years ago when personal computers could not handle large images, good USMed images all came from heavy-duty dark room work. Thanks to Moore's law, now USM is available for all amateur astronomers and does not take too much time. However, good digital USM results still require an understanding of this technique, in addition to just clicking the mouse bottoms. In this article, I will explain the underlying principals of this technique and show the readers how to apply these principals to USM your images.

Concept about Scales of Structures

Later I will use the term "scale of structures" frequently and I need to introduce this concept first. Let's look at Fig.1 and Fig.2, which show some 1-dimensional and 2-dimensional images. An image consists of structures of various size scales. For example, images in Fig.1a and Fig.2a can be decomposed into structures of smaller size scales (Fig.1b and Fig.2b) and structures of larger size scales (Fig.1c and Fig.2c).

Large-scale structures usually represent the overall brightness distribution of an image. A huge bright nebula or a bright Milky Way belt on top of the dark background is a good example of large-scale structure seen in a picture. Small-scale structures usually represent the detailed brightness variation in an image. Typical small-scale structures in astronomical pictures are stars. Other examples include the small structures in nebulae, contrast between arms and inter-arm regions of spiral galaxies, etc.

In principal, structures of different size scales in an image can be separated from each other, just like what is showed in Fig.1 and Fig.2. Why separating them? Large-scale structures that dominate the overall brightness distribution can usually be enhanced by simple brightness and contrast adjustments, such as *Levels*, *Curves*, and *Brightness/Contrast* tools provided by PhotoShop. On the other hand, these tools CANNOT enhance small-scale structures WITHOUT altering the large-scale counterparts. Any attempt to enhance small-scale structures with these tools will largely change the overall brightness profile. This will usually saturate the bright parts and produce a too contrasty picture. Therefore, to enhance the small details in our pictures, we need to separate structures of different size scales.

There are many separating method in nowadays professional image processing, called filters. These filters can filter out structures of some particular size scale (called "wavelength"), just like what photographic filters do on light. Photographers had figured out a method to do this in dark rooms long time ago, called "unsharp mask".

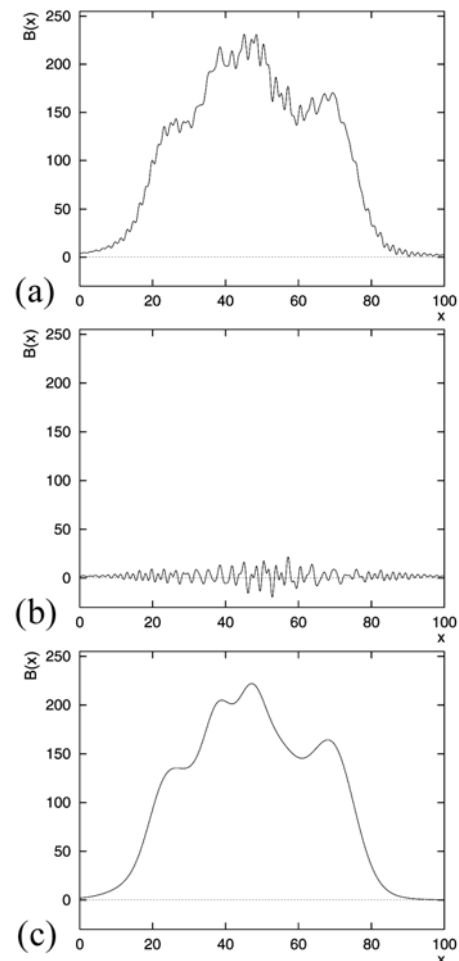


Figure 1 A 1-dimensional image. (a) is the original image. (b) shows the small-scale structures in (a) and (c) shows the large-scale structures in (a). $(a)=(b)+(c)$.

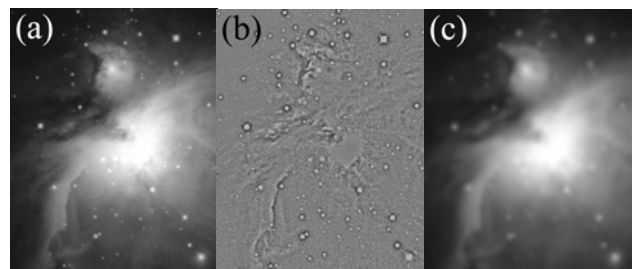


Figure 2 A 2-dimensional image. (a) is the original image. (b) shows the small-scale structures in (a) and (c) shows the large-scale structures in (a). $(a)=(b)+(c)$.

Unsharp Mask — the Image Containing Large-Scale Structures

The way that photographers filter out small-scale structures in dark rooms is to make a duplicate of the original negative, but with some blurring. The blurred duplication is called "unsharp mask" and of course does not contain any details (the small scale structures) in the original negative. The unsharp mask can then be applied to the original negative to subtract off some fraction of the large-scale components. This will

lead to an image that contains stronger small-scale signal. The whole dark room procedure is now called unsharp mask, the same as the name of the blurred duplication. (Hereafter I will use “unsharp mask” for the blurred duplications and “USM” for the full image processing procedure, to avoid some confusion.)

USM procedure in dark rooms is actually much more complicated than what is described above. However, this can be done easily with recent personal computers and commercial software such as PhotoShop. It is simple to produce an unsharp mask — just to blur the image. A standard way to blur an image (or to pick out the large scale structures) is *Gaussian Blur* in PhotoShop. The idea is to average all the pixels inside some certain radii and replace the original pixel value with the average. Thus, any structures smaller than the blurring radius will be smeared out and the blurred image (the unsharp mask) will only contain large-scale structures.

Unsharp Mask — the Enhancement of Details

Let's now take a closer look at how USM can enhance image details. Fig.3a shows a two-dimensional image. Fig.3b is the blurred image, the unsharp mask. If we subtract Fig.3b from Fig.3a, we will get Fig.3c, which contains only small-scale structures, i.e., the details. (Hereafter we will call this image the "residue" image after the subtraction of unsharp mask.) We can multiply the residue with a constant and get Fig.3d. This multiplication corresponds to increasing contrast in PhotoShop. The final step is to add together Fig.3d (the enhanced small-scale structures) and Fig.3b (the large-scale structures). The final image, Fig.3e, has stronger details but conserves the overall large-scale brightness profile. This cannot be done in any of *Levels*, *Curves*, and *Brightness/Contrast* tools in PhotoShop.

Fig.4 is the 2-dimensional equivalence of Fig.3. The readers can see how the details in this picture are enhanced by USM.

Unsharp Mask in PhotoShop

Each individual step in the procedure described above can be done in PhotoShop, using tools such as *Brightness/Contrast*, *Gaussian Blur*, and *Apply Image* or *Calculations*. A good news is that PhotoShop kindly provides everything above as a single filter tool. We can easily do USM in PhotoShop. However, some care is still needed in order to obtain the best results.

There are three parameters you can specify for USM in PhotoShop: *AMOUNT*, *RADIUS*, and *THRESHOLD*. The *AMOUNT* parameter is easy to understand, it corresponds to the multiplication factor used to enhance the small-scale structures, as described in the previous section (Fig.3c to Fig.3d or Fig.4c to Fig.4d). The best way to determine which value to use is simply to preview the image.

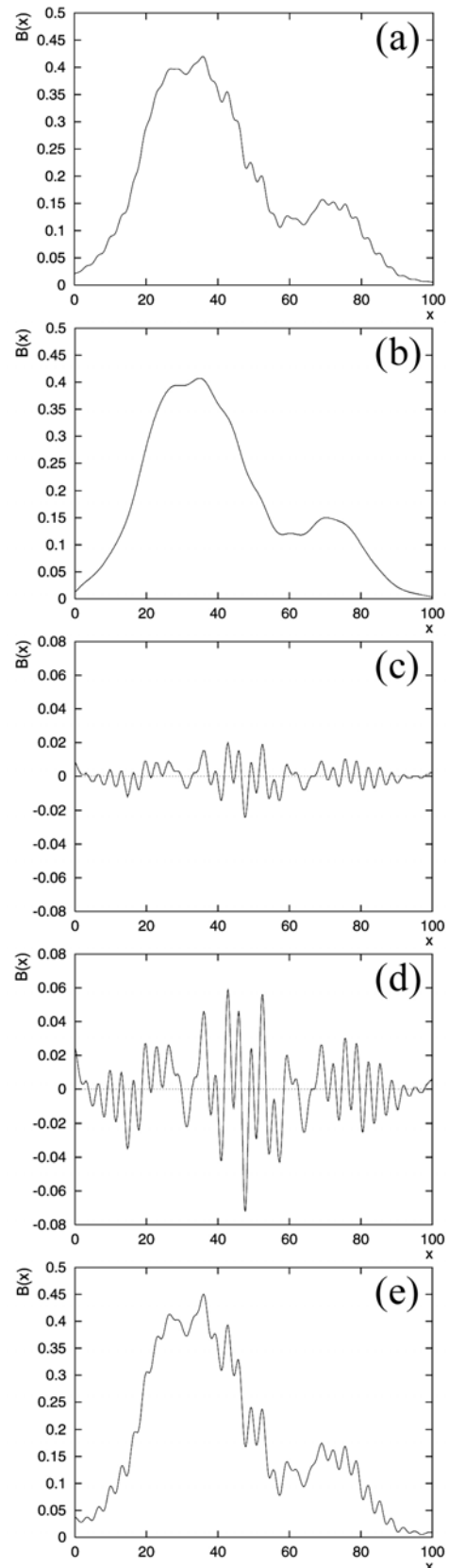


Figure 3 (a) Original image. (b) Blurred image, the unsharp mask. (c) $= (a) - (b)$, the small scale structures in (a). (d) $= (c) \times 3$. (e) $= (d) + (b)$. We can see that the small-scale structures (the details) are enhanced but the overall brightness profile is conserved. The bright part of this image will not saturate in this process.

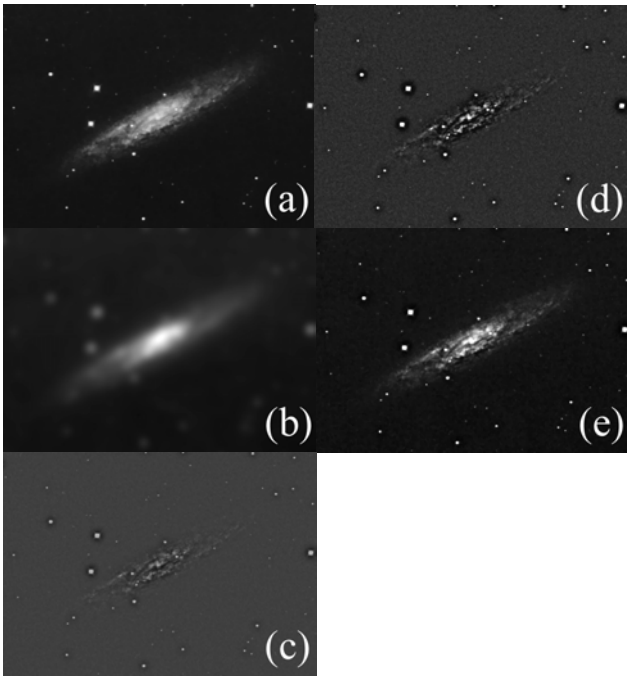


Figure 4 2-dimensional equivalence of Fig.3. The meaning of each sub-panel in Fig.4 is the same as in Fig.3.

The real magic in PhotoShop USM is the *RADIUS* parameter. It is not trivial to understand the effect of this parameter. Previewing and trial and error are possible solutions to manage it, especially given that computers today are fast enough to allow this. However, it is still good to know how to choose the *RADIUS* value correctly and to be able to anticipate the results just by our brain.

The *RADIUS* you use should be approximately the size scale of the structure that you want to enhance.

In other words, structures that are much larger than the *RADIUS* or much smaller the *RADIUS* will NOT be enhanced by USM. Let's look at larger scales first. The *RADIUS* parameter in PhotoShop USM is actually the radius for Gaussian blurring. Recall what I said earlier, structures smaller than the radius will be smeared out by Gaussian blurring. Thus only scales larger than the blurring radius will exist in the unsharp mask. These larger scale structures will later be subtracted from the original image and therefore will not be enhanced, as shown in Fig.3 and Fig.4.

It's usually true that structures smaller than the radius will not be enhanced by USM. In most cases, larger-scale structures have larger brightness variation, comparing to smaller scale structures. If we multiply a constant to an image, the visual effect is stronger for larger brightness variations and thus for the larger-scale structures. Therefore, if the residue image is multiplied by a constant, the strongest enhancement will be on the larger scale structures in the residue. This is approximately the scale of the blurring radius used to generate the unsharp mask.

Combining the arguments above, we come to the conclusion that only structures with size scales similar to the *RADIUS*

will be enhanced by USM. This is shown in Fig.5. We can see that a larger *RADIUS* parameter will enhance larger scale structures. Therefore, when determining what *RADIUS* value to use, one should ask himself: what is the size of the structure I hope to enhance?

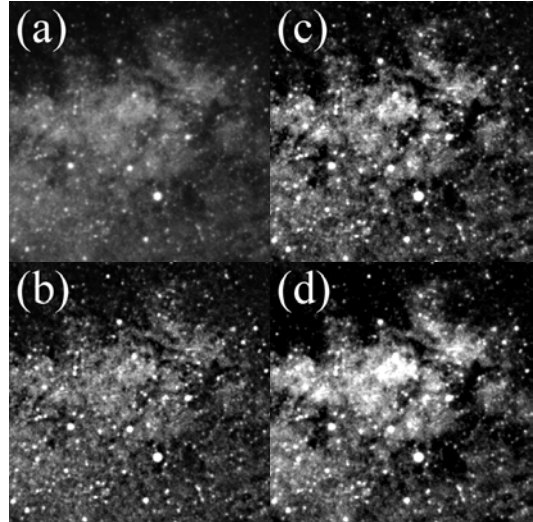


Figure 5 Examples of USM with identical *AMOUNT* parameter but different *RADIUS* parameters. (a) The original image. Pixel dimension is 400×400. (b) *RADIUS*=6. In this image, the stellar images and the smallest dark clouds are best enhanced, since they have size scales close to 6 pixels. (c) *RADIUS*=20. Most of the dark cloud structures in this image are well enhanced. This is perhaps the most suitable *RADIUS* parameter for this image. (d) *RADIUS*=80. Structures of all size scales are enhanced. This image is similar to the result of changing contrast directly.

For example, if one is dealing with a crowded stellar field and hopes to better separate the stars from each other, he should use a *RADIUS* similar to the sizes of stars in the image. Then the USM will enhance the brightness profile of each stellar image. If one is dealing with a picture of spiral galaxy and hopes to enhance the contrast between the spiral arms, he should first measure the width of the spirals in the picture and try *RADIUS* values close to the width.

Because there are so many different structures existing in an image, sometimes it is necessary to do USM for more than one time and with different *RADIUS* values. The *RADIUS* values I usually use range from 5 to greater than 100, totally depending on the size of the structure I would like to enhance. It is important to note that it does not make sense to use a *RADIUS* smaller than the smallest stars in an image. The smallest stars define the resolution of the image. Any structures smaller must be just noise. We don't want to enhance them.

The last parameter we can play with is the *THRESHOLD* parameter. When multiplying (enhancing) the residue, only pixels brighter than *THRESHOLD* (or darker than negative *THRESHOLD*) will be multiplied. The multiplication

shown from Fig.3c to Fig.3d is actually for $THRESHOLD=0$. If $THRESHOLD$ is non-zero, the multiplication will look like in Fig.6.

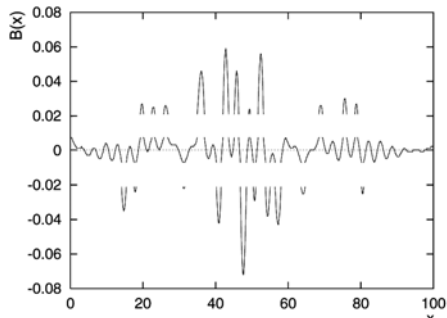


Figure 6 Fig.3c \times 3, but with $THRESHOLD=0.007$. Only pixels with absolute values greater than 0.02 in Fig.3c will be multiplied.

The purpose of setting a non-zero $THRESHOLD$ is to avoid amplifying the noise and just to amplify signals much stronger than the noise. I almost always set $THRESHOLD=0$. The main problem of a non-zero (especially a large) $THRESHOLD$ is that it usually produces some discontinue in brightness that does not look natural. Use this parameter with care. When one suffers from the problem of noise, he should look for other high quality (low noise) images. The $THRESHOLD$ parameter does not really help much.

Few More Words

It is very interesting to see all the different combination of USM and other image processing schemes. I will not discuss all these details here. However, I would like to suggest the readers to sometimes try the following: (1) Before applying USM, decrease the image contrast. Doing this is mainly to avoid saturation of bright parts. Interestingly, this may also help to enhance fainter details. (2) Try to work in PhotoShop *Lab* space, rather than normal *RGB* space. When you expect normal USM results, apply USM to the *L* channel (the brightness channel) only. This may reduce the enhancement of noise that could happen in *RGB* space. (3) If you hope to enhance the contrast between objects of different colors, try to apply USM to *a* or *b* channel (the color channel) in the *Lab* space. This will change the color distribution but conserve the brightness distribution.

The most exciting USM game one can play in PhotoShop is perhaps doing all the individual steps described in Fig.3 and Fig.4 by himself. A very good example is the so-called "revolutionary USM," which is commonly used on images of solar corona taken in total solar eclipse. The idea is the same as the normal USM, but only to enhance structures along some specific direction. The brightness distribution of solar corona is smoother in radial direction than in tangential direction. Thus, in order to better show the coronal structures, the optimal way is to only enhance the tangential brightness variation. This kind of special USM is not provided by

PhotoShop as a single tool. To do this, one can only do it step by step. The key is to generate the unsharp mask using the *Radial Blur (spin mode)* provided by PhotoShop to smear out the tangential structures.

Finally, let me emphasis again the importance of understanding the underlying principals. Only after fully understanding the tool, one can properly utilize it.

Happy USMing.



Figure 7 An example of USM results. This picture combines three images of different resolution and depth. USM is applied to each of the images to enhance different structures.