An Adaptive Homomorphic Aperture Photometry Algorithm for Merging Galaxies

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Abstract

We present a novel automatic adaptive aperture photometry algorithm for measuring the total magnitudes of merging galaxies with irregular shapes. First, we use a morphological pattern recognition routine for identifying the shape of an irregular source in a background-subtracted image. Then, we extend the shape of the source by using the Dilation image operation to obtain an aperture that is quasi-homomorphic to the shape of the irregular source. The magnitude measured from the homomorphic aperture would thus have minimal contamination from the nearby background. As a test of our algorithm, we applied our technique to the merging galaxies observed by the Sloan Digital Sky Survey and the Canada–France–Hawaii Telescope. Our results suggest that the adaptive homomorphic aperture algorithm can be very useful for investigating extended sources with irregular shapes and sources in crowded regions.

Key words: techniques: image processing – techniques: photometric

1. Introduction

An important issue in astronomical CCD photometry is obtaining an unbiased flux estimate for an extended source. Usually, a circular or elliptic aperture is used for estimating the total flux of a source. While the aperture must be sufficiently wide for including most of the flux from the source, its size should be limited in order to minimize the sky noise and avoid contamination from the nearby sources. Some adaptive schemes, such as aperture methods described by Kron (1980) and Petrosian (1976), have been proposed for optimization of results.

However, galaxy photometry is not a straightforward process. For galaxies in a crowded region or for irregular galaxies with odd shapes, it is difficult to obtain the “best” aperture. Automatic elliptical/circular apertures could include extra contributions from the nearby sources or miss the faint parts of the irregular galaxies. Sometimes, it is also difficult to separate the nearby objects with an elliptical or circular aperture in a crowded region. The uncertainties in the flux measurement not only stem from the background noise but also from the shape and size uncertainties of the integrating aperture itself.

Ideally, the sky noise could be minimized and the contamination from the nearby sources could be avoided if the aperture used is similar to or has the same shape as the source. Isophotal technique has been applied for similar purposes (Kibblewhite et al. 1984). However, isophotal apertures might miss the faint edges of the objects and thus could underestimate the flux measurements from the objects; a corrected isophotal aperture photometry has thus been proposed to correct the problem (Maddox et al. 1990). The corrected isophotal aperture assumes that the faint edge of an object is mainly affected with Gaussian atmospheric blurring; therefore, the total flux owing to the object can be derived from the isophotal aperture with a Gaussian blurring correction. The correction might be suitable for point sources; however, it has large uncertainty when applied to spheroidal galaxies (Bertin & Arnouts 1996). Moreover, the wing of atmospheric point-spread function was found to behave more like a power law rather than a Gaussian profile (Racine 1996).

For merging galaxies, which usually have more complex morphology, we would likely include additional background noise or contamination sources when applying elliptical apertures. Isophotal technique might be quite suitable for merging galaxies, but it might miss the faint structures of the merging galaxies. Currently, there is no suitable aperture technique that is specifically designed for merging galaxies. To achieve this goal, we provide a completely different algorithm by utilizing pattern recognition routines for obtaining an adaptive aperture which is enlarged from the original shape of the source by extending its boundary. We considered such an enlarged aperture is “quasi-homomorphic” to the original shape of the source. Such a quasi-homomorphic aperture is very suitable for estimating the total magnitudes of irregular galaxies or normal sources in crowded regions.

In this paper, we present a new technique for obtaining adaptive homomorphic apertures automatically by using...
pattern recognition routines. In Section 2, we describe the adaptive aperture photometry process in detail. This technique was applied to the merging galaxies observed in several survey projects, and the results are shown in Section 3. Finally, in Section 4, we discuss our results and summarize our methods.

2. Methodology

We developed a new algorithm for measuring the magnitudes of irregular objects by using adaptive homomorphic aperture photometry. The algorithm uses pattern recognition routines to create homomorphic apertures that are similar to the shapes of the irregular objects. The shapes of the sources and the apertures are identified in binary images, which are converted from the original CCD images based on detection thresholds. Our photometry processes include background subtraction, binary image creation and homomorphic dilations. The software for these processes was implemented in the Interactive Data Language.

2.1. Background Subtraction

Before measuring the flux of a source in a CCD image, the background has to be subtracted from the CCD image. A global background value is usually not representative of the entire CCD image. To do the background subtraction, we basically follow the background subtraction steps in the SExtractor package (Bertin & Arnouts 1996). Our algorithm first divides the CCD image into several grids (usually 200 × 200 pixels for one grid) in order to get the local background values. After rejecting the outliers, the algorithm estimates the mode (Mode = 3 × Median − 2 × Mean, Kendall & Stuart 1977) and the standard deviation for each grid. The algorithm applies a 3 × 3 median filter on the grids to reduce the overestimation around bright objects. In other words, for each grid the algorithm selects the median value of its eight neighbors to replace the value of that grid. The algorithm applies the bi-cubic-convolution interpolation to the entire CCD image to construct a smooth background map and a standard deviation map for background subtraction and following processes.

2.2. Binary Image Process

The algorithm sets a threshold on the background-subtracted image to create a binary image. A specific pixel value will be set to 1(0) if the corresponding pixel of the background-subtracted image has a value higher (lower) than the local threshold. In the algorithm, the threshold is a free parameter, measured in units of local standard deviation $\sigma_{sky}$. The default threshold is 1.5 $\sigma_{sky}$ in order to retain the faint structures of the sources. In the binary images, a group of connected pixels that exceed the threshold value is considered as an object.

To identify real sources, the algorithm applies the smoothing operator Opening on the binary image. The operator Opening is a combination operator of the image operators Erosion and Dilation, which are two basic image operators in the area of mathematical morphology (Soille 2003). The effect of Dilation/Erosion on a binary image is to enlarge/reduce the boundaries of the objects. Graphical illustrations of these processes are shown in Figure 1. The operator Opening will eliminate the objects that are due to background noise fluctuations; these fake sources are usually have the sizes less than 5 pixels in the binary images. Such a smoothing process might not reduce some noise that is correlated, but the correlated noise will not affect on the photometry of real sources. The Opening operator also disconnects the weak links between the object and nearby sources in the binary image. After completing the Opening, the remaining group of connected pixels will be considered as a real object, and its coordinates will be set at the geometric center of the connected pixels.

2.3. Homomorphic Dilations

The adaptive aperture uses an irregular aperture that is quasi-homomorphic to the real shape of a source. For an irregular source, the source’s shape can be derived from the binary image. However, the flux of a galaxy decreases slowly as a function of radius and parts of the flux could be below the detection threshold, especially on the edges of the galaxy. To capture most of the flux of an irregular object, our algorithm takes the object’s shape in the binary image to be its original shape and increases the aperture size in a quasi-homomorphic manner, implying that the aperture’s size is enlarged while trying to preserve the original source’s shape. The quasi-homomorphic extension of
the aperture is implemented by using the Dilation operator. The Dilation operator can be applied more than once for obtaining the best estimate of the flux.

The “best” size of the aperture should be the smallest size that captures all of the source’s flux. For an isolated normal galaxy, this technique should yield the same results as other aperture techniques. We selected several known normal galaxies, which have well-defined photometric information, for examining the relation between the flux measurements and the aperture sizes for several different instruments. The sizes of the apertures could be determined by comparing our results with the results for these known galaxies. Because of the different sensitivity and observation conditions at different observations, the best aperture size for different instruments might be different. The number of Dilation was set as a free parameter in the algorithm, for determining suitable aperture sizes for different observational data. Once the number of dilations has been decided, the technique can be used for obtaining the flux of the source. Figure 2 illustrates some examples of the adaptive homomorphic apertures.

3. Application

For testing the proposed method, we applied the algorithm on the Sloan Digital Sky Survey (SDSS, York et al. 2000; Stoughton et al. 2002) images and the Red Sequence Survey 2 (RCS2, Gladders & Yee 2000) images. We selected a group of known isolated normal galaxies for determining suitable parameters for the images. We then applied the method by using these parameters for measuring the magnitudes of merging galaxies.

The SDSS Database provides well-calibrated background-subtracted images. To test our algorithms, we selected 3219 isolated normal galaxies from the SDSS Data release 9 and 42 mergers from the Galaxy Zoo project (Lintott et al. 2011). Figure 3 shows the flux measurements with the adaptive apertures of different Dilation operations for these 3219 isolated galaxies. We note that the aperture size will become larger with more Dilation operations. The results indicate that the best aperture sizes require four Dilation operations with the threshold of 1.5 \( \sigma_{\text{sky}} \). We applied the parameters to obtain the apertures for the 42 mergers, which were identified as interacting systems with SDSS photometric results for each individual galaxies. We compared our results with the SDSS Petrosian measurements. Since we only measured the total flux of the merging galaxy system, we summed the SDSS Petrosian flux of individual galaxies in the system for comparison. As shown in Figure 4, for these irregular objects, our algorithm was able to detect more flux from the objects, presumably originated from faint structures of the objects, than did the Petrosian aperture technique.

Hwang & Chang (2009) have found more than 13,000 merging galaxy candidates by analyzing the RCS2 images. The RCS2 images were observed by the Canada–France–Hawaii Telescope with the wide-field imager “MegaCam” (Magnier & Cuillandre 2004). We adopted the adaptive homomorphic
aperture method for retrieving the photometric information of these merging galaxy candidates. We used 1081 isolated normal galaxies for estimating the best dilation number in determining the size of the homomorphic apertures (Figure 5). The empirical test shows that the best size of an aperture requires 2 homomorphic dilations. With these parameters, the photometric information on the $g'$, $r'$, and $z'$ bands for 13,290 mergers out of the 13,577 candidates has been successfully obtained (Figure 2). For the 287 failure cases, 102 were owing to the pollution of cosmic rays; 110 sources had objects in immediate neighborhood, which were less than 0.6 (∼3 pixels) away from the edges of the sources; the rest were owing to false background subtraction.

4. Discussion

We developed an adaptive homomorphic aperture technique for the flux measurements of irregular objects. This technique needs to decide suitable parameters in determining the best size of an aperture. We can use a catalog of artificial sources or a group of known isolated galaxies with regular shapes to decide the suitable parameters. To contain minimum noise, the adaptive homomorphic apertures should be as small as possible but would capture the flux of the sources as much as possible. For irregular objects, this method might also contain faint structures of the sources, which might not be included by other automatically aperture techniques. Our test showed that our algorithms could capture more flux for merging galaxies than did the Petrosian aperture technique (Figure 4), whereas these two techniques demonstrated similar results for normal galaxies (Stoughton et al. 2002). This results indicate that the adaptive homomorphic apertures can be useful for measuring faint structures, which are not accounted for by using the Petrosian aperture.

In the algorithms, the threshold and the number of Dilations are two main parameters that need to be decided. Threshold value will determine the shapes of the objects. Using high threshold values can minimize the contamination of background noise and separate very nearby sources but may lose the structure information at the edges of the objects. Through the test for the known isolated galaxies with regular shapes, we found that the threshold value and the number of Dilations are not independent; using high threshold values need more Dilations in order to have more accurate estimation of the flux of the source.

The adaptive homomorphic aperture technique requires different number of Dilations for yielding the best aperture sizes for images with different sensitivity and resolutions. Our tests showed that the number of Dilations for the SDSS images is four; however, under the same threshold condition, the number of Dilations for the RCS2 images is two. The differences might be caused by the higher sensitivity and the better seeing of the RCS2 images than those of the SDSS images. The method might require a group of known isolated galaxies with regular shapes for empirically deciding the suitable parameters.
The suitable number of Dilation operations will be affected by the seeing; the dilated regions need to be greater than or similar to the seeing. The adaptive homomorphic aperture technique is also useful for objects located in the crowded regions. Many merging galaxies in the RCS2 images were detected with additional nearby objects. The median seeing of the RCS2 images is about 0.7 and the pixel sizes are about 0.2. With these observational conditions, we found that the homomorphic apertures can avoid contaminations from the nearby objects as long as the nearby objects are more than 0.6 away from the edges of the sources.

The images in different observing bands may require different parameters in creating the best adaptive homomorphic apertures. This might cause a problem when estimating the colors of objects since the detected areas on different images are different. To avoid this problem, we used a common aperture for the flux measurements of an object in different observing bands. The basic shape in creating the common aperture of an object was the union of three basic shapes from aligned images of different observing bands.

This technique is similar to the isophotal technique (Kibblewhite et al. 1984; Bertin & Arnouts 1996). The isophotal aperture photometry determines the aperture sizes by considering the pixels that have signals above the detection threshold, which is similar to the sizes of the original objects in the first step of the binary image process in our algorithm. Generally speaking, the isophotal technique might miss the faint structure of an object and might underestimate the total flux of the object. There is a corrected isophotal aperture photometry attempting to correct the problem theoretically (Maddox et al. 1990). The corrected isophotal aperture assumes that the faint edges of the object mainly stem from the Gaussian atmospheric blurring; thus, the total flux of the object can be derived from the isophotal aperture photometry by applying the correction relation. On the other hand, our algorithm avoids this problem by using the homomorphic dilation process. We applied these three aperture photometry techniques on the...

Figure 5. Left: measured flux ratio distributions of 1081 galaxies from the RCS2 images with different aperture sizes (different dilations). The measured flux ratio is defined as the ratio of the measured adaptive homomorphic aperture (AHA) flux and the SDSS Petrosian’s flux. The red, green, black, and purple lines represent the photometric results measured by using the adaptive apertures with 0, 2, 4, 6 homomorphic dilations (NoD). Right: mean flux ratios for different aperture sizes. The error bars show the standard deviation of the measurements.

Figure 6. Left: measured flux ratio distributions of 3219 galaxies in the SDSS images by using different aperture methods. The measured flux ratio is defined as the ratio of the measured flux from different methods to the SDSS Petrosian flux. The red lines are the results for the isophotal apertures (Isophot), the purple lines are the results for the corrected isophotal apertures (CorIso), and the black lines are the results for the adaptive homomorphic apertures (AHA). Right: measured flux ratio distributions of 1081 galaxies in the RCS2 images by using different aperture methods. The methods and symbols of the measurements are the same as those of the left diagram for the SDSS images.
isolated normal galaxy samples of the SDSS and the RCS2 for examining their performance (Figure 6). We found that the results obtained by using our algorithm are comparable with the results of the corrected isophotal technique for the RCS2 galaxies; however, for the SDSS sources, the results obtained by our algorithm are consistent with those of the Petrosian results, whereas both the isophotal and corrected isophotal results seem to underestimate the true flux. These results suggest that the adaptive homomorphic aperture technique works well for different observations and the photometry information can be acquired in a straightforward manner.

The adaptive homomorphic aperture technique is applicable to irregularly shaped extended sources and is also useful for sources in crowded regions. However, it might be necessary to decide the best number of dilations empirically for different instruments. Once the number of dilations has been decided for specific observation data, the algorithms can be used for obtaining the flux of the sources.

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