AUTOMATIC CHARACTERIZATION OF SPIRAL AND ELLIPTICAL GALAXIES AND RECOGNITION OF STRUCTURES

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ABSTRACT

In this work, we perform the automatic characterization of spiral and elliptical galaxies by extracting morphological features determining a galaxy. Taking into account that the appearance of spiral arms is enough to characterize the galaxy as belonging to the family of spiral galaxies, it will be possible to reduce the automatic characterization problem to that of detecting the presence or absence of arms in an appropriate region in the galaxy. Bars and arms recognition on spiral galaxies from digital images, is also analyzed.

1. Segmentation Process

Our interest is to reduce the galaxy classification problem to the simpler problem of studying the deformations present on a closed contour obtained from a segmentation process of the grey level image. An initial segmentation is obtained by statistical thresholding. We consider four different regions: (a) let $Class$ 1 be the high grey-level value pixels defining the center of the galaxy -$Center$-, (b) let $Class$ 2 be the medium grey-level value pixels defining the intermediate zone, (c) let $Class$ 3 the low grey-level value pixels defining the background, and (d) let $Class$ 4 be a fourth class between classes (b) and (c). To clean the initial segmentation, we use a smoothing procedure.

2. The Characterization Methods

The curve C that, containing the center of the galaxy, $Center$, defines the boundary between $Class$ 2 and 3 regions, exhibits deformations due to the arms on spiral galaxies (Figure 2.B and 2.E), but shows nearly elliptical shape on elliptical galaxies. Taking into account these properties of C, an approach to discriminate the elliptical galaxies is obtained by using the the distance $D(C, E)$ between the curve C and the ellipse E fitted to C, which is defined as

$$D(C, E) = \frac{area(R_C \cup R_E - R_C \cap R_E)}{area(R_C \cup R_E)} \tag{1}$$

R_E being the region enclosed by E and where $area(\cdot)$ denotes the area of the corresponding region.

When the contour C is extracted from spiral galaxies, the graph of the curvature values $K = \{k(i) \mid i = 1, \cdots, n\}$ shows strong oscillations. This behaviour is not

*A extended version of this work can be obtained mailing to the authors.

present when we analyze curves from elliptical galaxies. Let $C^{+}_{deformed}$ (respectively $C^{-}_{deformed}$) be a contour fragment (of the curve C), which is deformed due to the presence of a spiral arm with positive (resp. negative) curvature. Let

$$p_{+}(s) = \begin{cases} \phi_1 h(s,\sigma) & s \leq 0 \\ \phi_2 h(s,\sigma) & s > 0 \end{cases} \tag{2}$$

where ϕ_1, ϕ_2 are two positive real numbers, and $h(s,\sigma) = \frac{s}{\sigma^2}\frac{1}{\sqrt{2\pi}\sigma}\exp\left\{-\frac{s^2}{2\sigma^2}\right\}$, and and let $p_{-}(s) = -p_{+}(s)$. The functions, $p_{+}(s), p_{-}(s)$, show around zero qualitative deformations similar to those ones produced on the graph of curvature values K by the presence of arms in spiral galaxies, and so can be used as templates to match possible arm occurrences.

3. Bars Recognition on Spiral Galaxies

The bar pattern is made by combining of two rectangular sectors, $S_{(x,y)}$ and $S_{(-x,-y)}$, radiating from a circunference $C(r)$ of radius r centered at the galaxy center, where (x,y),$(-x,-y)$ in $C(r)$. Let $B_{(x,y)}$ be the pattern corresponding to the $S_{(x,y)}$ and $S_{(-x,-y)}$ sectors, which is defined as $B_{(x,y)}(i,j) = \begin{cases} \mu_1 & \text{if } (i,j) \in S_{(x,y)} \cup S_{(-x,-y)} \\ 0 & \text{otherwise} \end{cases}$ μ_1 being the mean gray-level on the class of pixels near to the galaxy center. The goodness of fit between the pattern $B_{(x,y)}$ and the image, is defined as $b_r(x,y) = \frac{1}{|S_{(x,y)}|+|S_{(-x,-y)}|}\sum_{(i,j)\in S_{(x,y)}\cup S_{(-x,-y)}}\left(x^{G}_{(i,j)} - \mu_1\right)^2$, with $x^{G}_{(i,j)}$ being the gray-level value on the pixel (i,j).

Let r^* be the radius of the circunference $C(r^*)$ more near to the frontier of the galaxy nucleus. To determine the presence or absence of bar on the galaxy, we use the statistic $\frac{S_1^2(r^*)}{S_2^2(r^*)}$, $S_1^2(r^*)$ being the goodness of the best fit of a pattern radiating from $C(r^*)$, and, $S_2^2(r^*)$ being the goodness of the worst fit of a pattern radiating from $C(r^*)$. The distribution of the statistic $\frac{S_1^2(r^*)}{S_2^2(r^*)}$ is a non-central $(0,\lambda)$ F-Snedecor. To extract the bar on a barred galaxy, new rectangular sectors are added to the best fit of a pattern radiating from $C(r^*)$, until a halt criterion is satisfied (Figure 1).

4. Arms Recognition

We believe that it will only be possible to extract the spiral structure of arms on spiral galaxies, by incorporating some kind of global notion of shape[2]. To extract an arm from the galaxy image, firstly we must capture the global geometry for its spiral structure, which can be formulated by the equation $r = a\exp b\theta$, a being the distance to the center of the galaxy, and b being the size of the angular increment. Secondly by using a known technique[3], the local geometry for the arm (the local variations of the pattern modeling the arm) is captured by iterative simulation. We obtain the global geometry for an arm as the logarithmic spiral with its origin in the galaxy center, fitting the contour fragment $C^{+}_{deformed}$ (respectively $C^{-}_{deformed}$) which is deformed due to this spiral arm with positive (resp. negative) curvature (Fig. 2). Let us suppose

the pattern p_+ has been fitted on the graph of curvatures K, taking the maximum value $k(t'')$. Let $T_+^{\uparrow}$ be a subset of T, being T the set of index associated to the graph of curvature values, where $t \in T_+^{\uparrow}$ if the curvature value $k(t)$ would be fitted by a value belonging to the positive and increasing fragment of the pattern p_+. Let B be the fragment of C, $B = \{(x(t_i), y(t_i)) \in C \mid t_i \in T_+^{\uparrow}\}$, and let B' be a set defined as

$$B' = \left\{(r(t_i), \theta(t_i)) \mid r(t_i) = \sqrt{x(t_i)^2 + y(t_i)^2}\ ,\ \theta(t_i) = \arctan \tfrac{y(t_i)}{x(t_i)}\ , t_i \in T_+^{\uparrow}\right\}.$$

The global geometry to an spiral arm is formulated as the logarithmic spiral $r = a^* \exp b^*\theta$, where $b^* = \frac{1}{\theta_2 - \theta_1} \ln \frac{r_2}{r_1}$ and $a^* = r_1 \exp\left\{-\frac{\theta_1}{\theta_2 - \theta_1} \ln \frac{r_2}{r_1}\right\}$, with (r_1, θ_1), (r_2, θ_2) being two elements of B'.

5. References

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2. J.A. Garcia, R. Molina, and N. Pérez de la Blanca, *Non-supervised characterization of galaxies using different approaches*, (Pattern Recognition and A. I., World Scientific Publishing, 1, 1992), pp. 145-154.

3. B. D. Rip , *Finding spira galaxies.* (Phil. Tr 1990), pp. 47

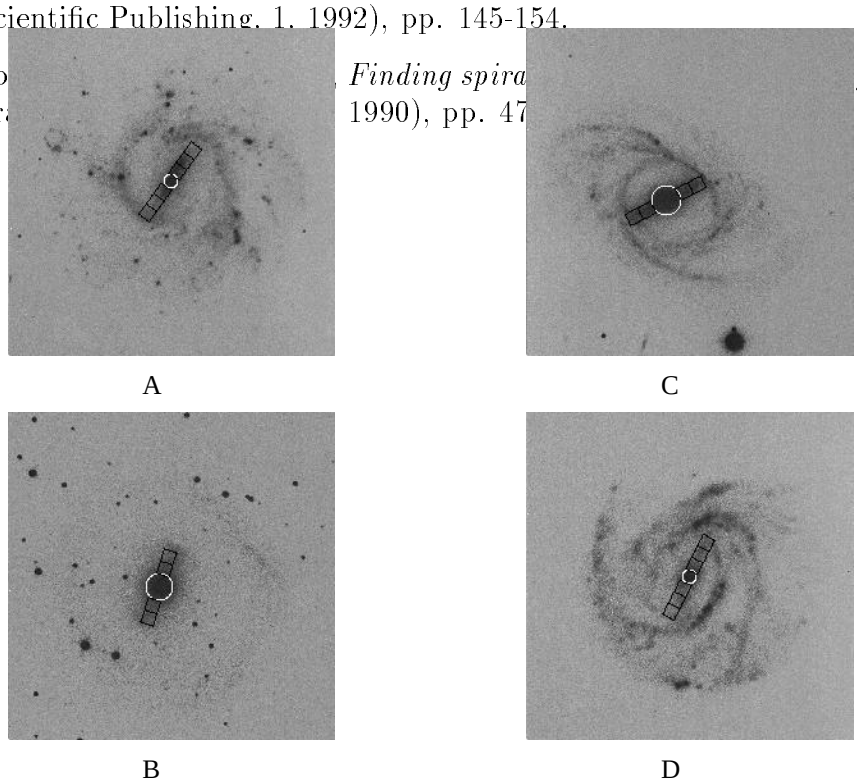

Figure 1: *A,B,C,D show the bars extracted on NGC-1073, NGC-2217, NGC-2523, NGC-3367.*

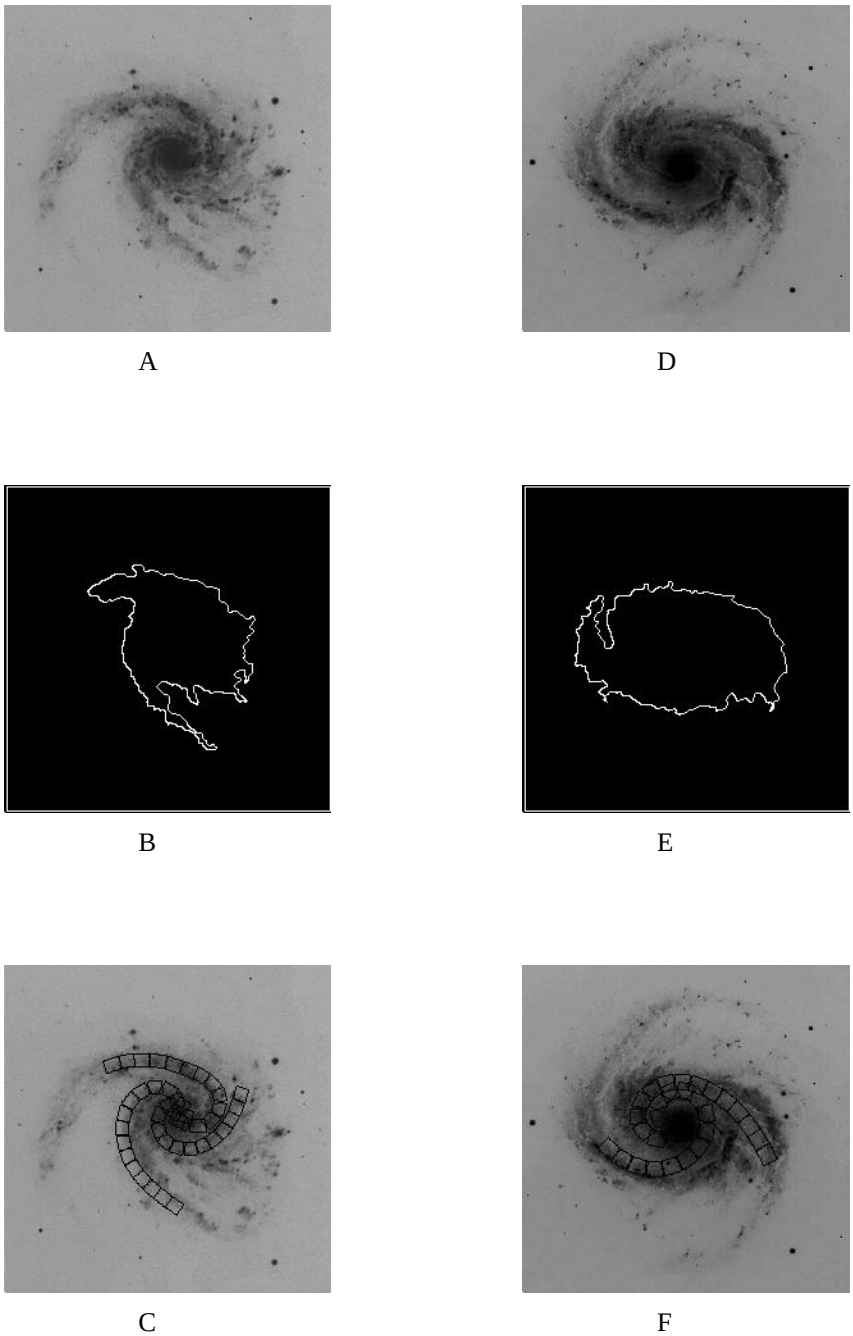

Figure 2: *B (respectively E) shows the boundary which is obtained on A (resp. D). C,F show the spiral arms exhibiting the global geometry which can be extracted for arms respectively on A,D.*