ESTIMATING CROWD DENSITY WITH MINKOWSKI FRACTAL DIMENSION

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ABSTRACT

The estimation of the number of people in an area under surveillance is very important for the problem of crowd monitoring. When an area reaches an occupation level greater than the projected one, people's safety can be in danger. This paper describes a new technique for crowd density estimation based on Minkowski fractal dimension. Fractal dimension has been widely used to characterize data texture in a large number of physical and biological sciences. The results of our experiments show that fractal dimension can also be used to characterize levels of people congestion in images of crowds. The proposed technique is compared with a statistical and a spectral technique, in a test study of nearly 300 images of a specific area of the Liverpool Street Railway Station, London, UK. Results obtained in this test study are presented.

1. INTRODUCTION

The management and control of crowds is a crucial problem for human life and safety [1,4,12]. One important aspect of the correct management and control of crowd is the real-time monitoring of crowds, which is usually carried out by means of extensive closed-circuit television systems and human observers. In order to prevent accidents, mainly in routine monitoring, such as those carried out in airports, train and subway stations, the automation of this job is a necessity.

This paper presents a technique for automatic crowd density estimation based on Minkowski fractal dimension of the image of the area under monitoring. Fractal geometry provides an elegant framework that can be taken as basis for a theoretical analysis and characterization of complex curves exhibiting some kind of intrinsic self-similarity at different magnification scales [8].

The self-similarity dimension (also known as box-counting or Minkowski dimension) provides a measure of the degree of 'space-filling' exhibited by a particular fractal curve [15], and has been increasingly applied as a means of characterizing data texture and shape in a large number of physical and biological sciences [2,5,11,13].

This paper is organized as follows. In Section 2 we present the technique for crowd density estimation based on Minkowski fractal dimension. In Section 3 we discuss how the fractal dimensions of crowd image can be estimated by means of Minkowski sausages. In Section 4 we present the results obtained by the new technique and compare them with results obtained by two other techniques: one statistical and one spectral. Finally, in Section 5, we summarize our work and findings.

2. CROWD DENSITY ESTIMATION

Figure 1 shows a diagram of the proposed technique for crowd density estimation by using the Minkowski fractal dimension. First, it is carried out edge detection in the input image and a binary image is generated. Next, n dilations are computed from the binary image with structuring elements of different sizes, ranging from 1 to n. From these dilations, it is estimated the fractal dimension of the input image (see details in Section 3). Finally, the fractal dimension is used as the feature to classify the image as belonging to one of the five following classes: VL – very low density; L – low density; M – moderate density; H – high density; or VH – very high density.

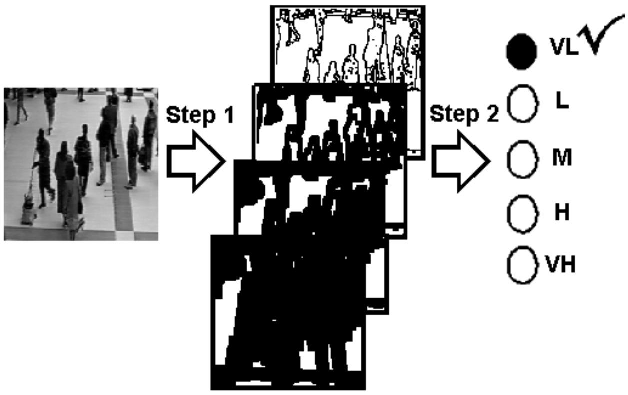

Figure 1. Diagram of the technique for crowd density estimation by using Minkowski sausages. Step 1: detects the edges of the input image; calculates the sausages from the binary edge detected image using structuring elements of different sizes. Step 2: estimates the fractal dimension from the sausages; classifies the input image into one of the five level of crowd densities: VL (very low), L (low), M (moderate), H (high), or VH (very high), using the fractal dimension as the feature.

These five classes can be considered *levels of service* as those proposed by Polus [14]. Polus' levels of service are: free flow, restricted flow, dense flow, very dense flow, and jammed flow, where each level is defined according to the number of pedestrian per area (peds/m^2).

3. MINKOWSKI FRACTAL DIMENSION

In the Minkowski approach for measuring the fractal dimension of a boundary, a circle is swept continuously along the line and the area which is covered, called Minkowski sausages, is determined. The value is then plotted as a function of the circle radius, and the slop (on the usual log-log plot) is used to estimate the fractal dimension [15].

Figure 2 shows, in the top row, two images of crowds. The left one, #1, is an example of very low crowd density (VL), and the right one, #2, is an example of very high crowd density (VH). The other rows show some Minkowski sausages, generated by using dilation operations with structuring elements of different sizes 1,3,7, and 11.

Looking at the sausages of Figure 2, it is possible to observe that the filled area of the image grows as the size of the structuring element also grows, until to reach the total area of the image.

Figure 3 shows the log-log plot of the Minkowski sausages for images #1 (denoted as O's) and #2 (denoted as +'s), determined by using structuring elements of sizes ranging from 1 to 15. This figure also presents the straight lines, with slope D_1 and D_2, determined by linear regressions of the log-log plots of the 15 Minkowski sausages computed for the two images. The fractal dimensions of the images #1 and #2 are then determined as being $2\text{-}D_1$ and $2\text{-}D_2$, respectively.

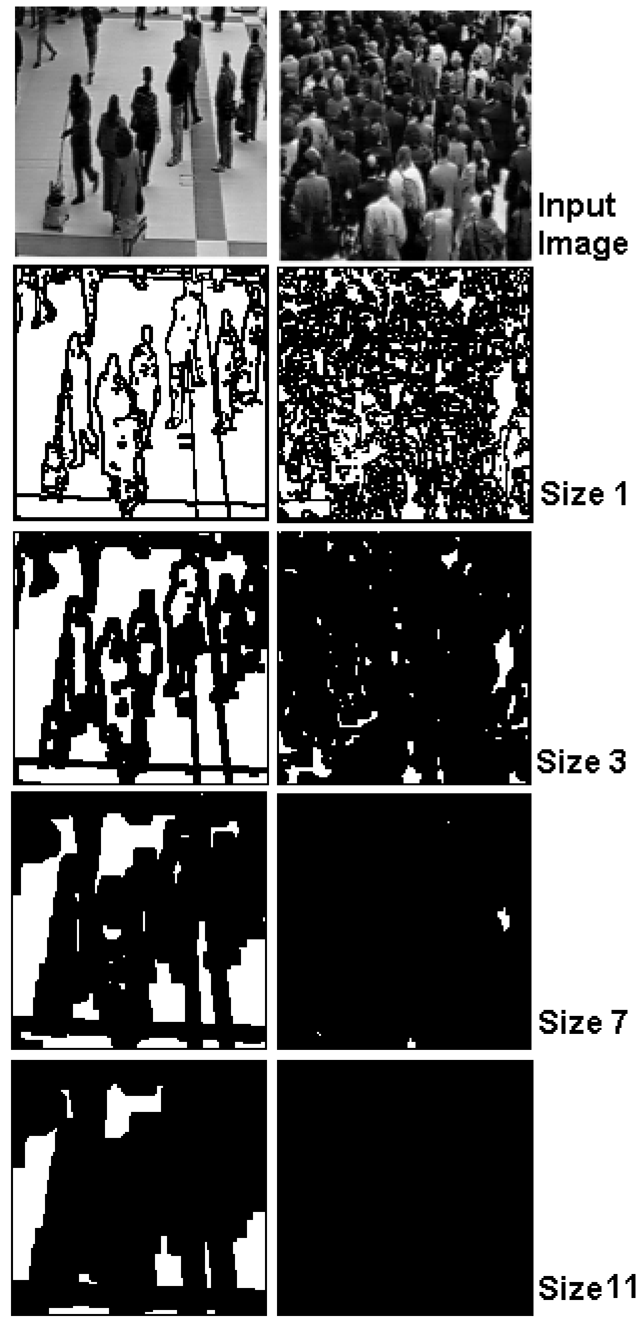

Figure 2. Two images of different crowd densities (top row) and their respective Minkowski sausages, obtained by using structuring elements of size 1 ,3, 7, and 11. Left image (#1): very low crowd density. Right image (#2): very high crowd density.

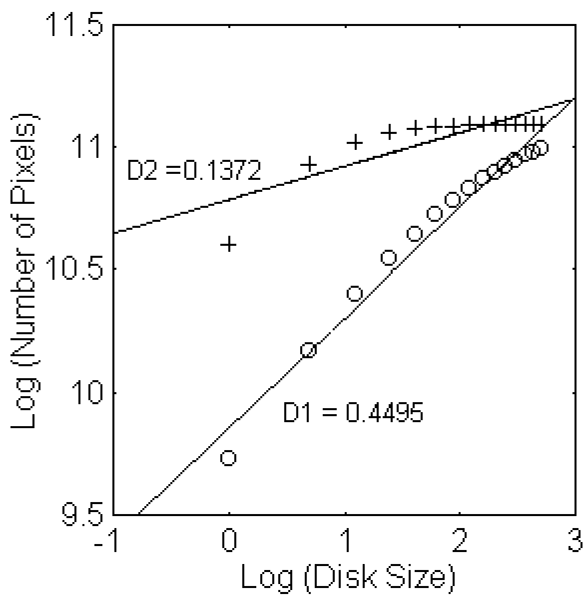

Figure 3. Linear regression of the log of the disk size and the log of the number of pixels, of 15 Minkowski sausages of two crowd images. O: image #1 (very low density) - fractal dimension = 1.5505; +: image #2 (very high density) - fractal dimension = 1.8628.

4. RESULTS

This section presents some results of our experiments in a test study of a set of crowd images captured in a specific area of the Liverpool Street Railway Station, London, UK. For all these images, it was manually estimated the number of people. These values were then used as a comparison standard with the values automatically estimated. Next, the images were separated into five classes, according to the manual estimated values: 61 images of very low density (from 0 to 15 people), 78 images of low density (from 16 to 30 people), 52 images of moderate density (from 31 to 45 people), 36 images of high density (from 46 to 60 people), and 64 images of very high density (more than 60 people).

In order to compare the results obtained with the Minkowski fractal dimension feature, we also implemented a gray level dependence matrix (GLDM) method and a Fourier spectrum method [6].

For the GLDM method, we used four matrices, taking d=1 pixel, and $\theta=0^o,45^o,90^o$, and 135^o. From such matrices we extracted four measures: entropy, energy, contrast and homogeneity, making up 16 features. For the spectral method, we used 24 measures extracted from the Fourier spectrum, by summing up spectral values in 16 radial directions and 8 concentric rings around the spectrum origin [9,10].

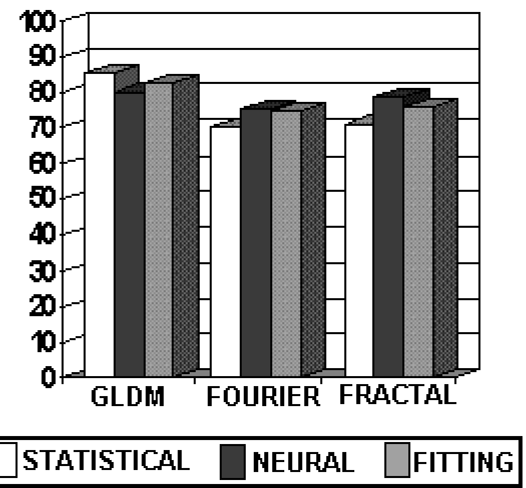

Figure 4. Results obtained by using three classifiers (statistical, neural and based on fitting functions), with feature vectors provided by three different methods: gray level dependence matrices, Fourier spectrum and Minkowski fractal dimension.

We also carried out an assessment of three different classifiers: statistical (Bayesian), neural (implemented according to Kohonen's self-organization map model [7]), and based on fitting functions.

We adopted supervised classification. Thus, a half of the set of images were used as training set, while the other half was used as test set.

Figure 4 shows the results obtained with features of the three methods (GLDM, spectral and Minkowski fractal dimension) and the three classifiers (statistical, neural and based on fitting functions). It can be observed that all methods provided correct classification rates above 70%, and that the better method was the GLDM, which provided the best rate (near 85%) when the statistical classifier was used. A favorable result observed in all tests was that the erroneously classified images were always assigned to a neighbor class of the correct one, allowing the methods to obtain mean estimations for each group very near to the expected values, with low variances.

The Minkowski fractal dimension provided the second better result, around 75% of correct classification. A deep analysis of this feature shows that this result could be improved if the classes H and VH were taken as a single level of service, since the classifiers were not able to segregate properly these two classes. Figure 5 presents a plot of the estimated fractal dimensions for the training images. This plot shows that the Minkowski fractal dimensions of the images of the classes H and VH make up, actually, a single cluster.

Due to the *limited (or partial) fractality* of the crowd images (these objects are not fractals in all possible scales), an improvement of the results could result from selecting the better sausages to estimate the fractal dimension. Coelho [3] presents an investigation of the effects of the limited fractality of real objects, and proposes practical guidelines that can lead to more precise and meaningful experimental results.

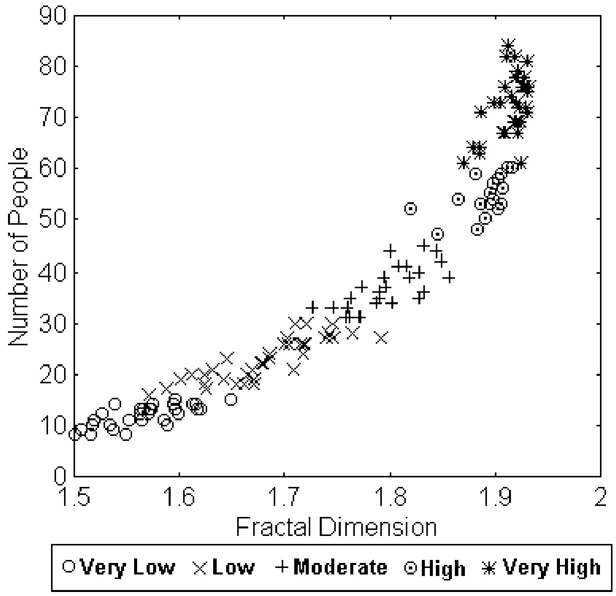

Figure 5. Relationship between the fractal dimension and the number of people in each image of the training set.

5. SUMMARY AND CONCLUSIONS

In this paper we have presented a new technique for automatic crowd density estimation by using Minkowski fractal dimension. Fractal dimension has been widely used to characterize data texture in a large number of applications. For the problem of crowd density characterization reported in this paper, fractal dimension results were comparable to traditional methods, like gray level dependence matrices and Fourier spectrum, with the advantage that it requires only one feature, in contrast with the other two, which requires, in general, several features.

The main difficulty found in our experiments with the use of the proposed fractal-based technique was that the classifiers were not able to distinguish between classes of high and very high densities. It suggests that it is necessary a deep analysis of which Minkowski sausages should in fact be used, in order to provide better estimation for the fractal dimensions. This problem is due to the partial fractality of the crowd images and is the subject of our current researches.

6. REFERENCES

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