Calculation of precipitation intensity using processing the sequence of video frames

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Abstract. The article describes the method for automatic precipitation detection and its intensity estimation from a sequence of video frames. The convolution operation used for filtration is optimized in order to decrease computational complexity. The accuracy of precipitation intensity estimation is improved by accounting for cross-correlation between sequential video frames. The proposed method has reduced computational complexity. The results of the study are demonstrated on a few images of different size. The computational complexity of proposed algorithm is appropriate for real-time implementation.

1 Introduction

Traditional methods for determining precipitation intensity directly measure the amount of precipitation collected in special devices, or calculate the number of precipitation droplets flying through the space between the plates of the measuring capacitors. These methods provide high accuracy of the measurements, but their applicability is significantly limited, because it requires special conditions to be hold during precipitation (minimizing the effect of wind on the device, as well as the effect of the station on the air flow, etc.). The other methods rely on probing the investigated area of the atmosphere by alternately sent laser, radar or acoustic pulses. However, such devices are expensive. They require special configuration, installation, maintenance and consume a lot of energy.

There are a few ways to obtain information about the presence of precipitation and its intensity by processing various video data. However, these methods are focused on processing video images collected with fixed cameras. They use stochastic models of a stationary background and their performance significantly degrades in presence of moving objects.

The method proposed in [1] for automatic detection of precipitation and its intensity estimation does not have these limitations. It does not require any specialized and expensive equipment and consider using a camera of the visible range mounted on a mobile carrier.

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However, this method has disadvantages. They are primarily associated with its computational complexity due to the use of multiple two-dimensional convolution operations with various filters (weights matrices). In addition, the disadvantage of this method is the dependence of the accuracy of the formed assessment of the intensity of precipitation on the size of the image obtained from the camera of the visible range.

Processing of a sequence of video frames can reduce the impact of these shortcomings, improve detection of precipitation and the accuracy of their intensity estimation, with the reduced computational complexity.

2 Improving the accuracy precipitation intensity estimation

The main reason for the decrease in the accuracy of precipitation intensity estimation is the dependence of the result of the algorithm on the image size. In the first three stages of information processing [1], two-dimensional convolution of images with 3x3 weights matrices is made and it is assumed that the longitudinal size of the rain lines is equal to one pixel of the image. The thickness of the rain lines will be not one, but several pixels in the case of high resolution images. In this regard, firstly, the wrong choice of the preferred direction of the rain lines is possible, and secondly, this will lead to an error in the numerical value of estimated precipitation intensity. Figure 1 shows areas of an image with precipitations of the same size; on the left image, the longitudinal size of the rain lines is more than one pixel.

Fig. 1. Sample images with different longitudinal dimensions of rain lines.

The result of applying method [1] to the left image of Figure 1 gives the estimated precipitation intensity of 3.041, which corresponds to the absence of rain. The same method applied to the right figure provides the estimate of 12.884, which corresponds to a rain of average intensity.

The considered problem is common in the detection of objects in an image; it has been considered in a few studies [2-4]. Two ways are proposed: either reduce the size of the image to such a value that the longitudinal thickness of the rain lines is equal to one pixel, or increase the size of the weighting matrices.

After analyzing both ways of solving the problem of reducing the accuracy of precipitation intensity estimation, it was decided to go for the first one, since increasing the size of the matrices requires multiplying the brightness of each image pixel by the filter coefficients M^2 times, where M is the matrix size. However, this change in the algorithm still negatively affects its computational complexity, since the processing of each video frame requires implementation of algorithm described in [1].

3 Reducing the computational complexity of the algorithm

Several steps have been proposed to reduce the computational complexity of the algorithm.

First, the size reduction factor is stored in the calculation and processing of the first frame of the video sequence to reduce the effect of changing image size on the computational complexity of the algorithm. For each next frame of the sequence, the calculation is not performed, but the reduction factor of the size from the first frame is used, and the remaining video frames are reduced by this number.

Second, we can assume that video sequences all have the same predominant direction of the precipitation lines, relying on the fact that they are correlated with each other. This allows reducing the number of steps performed by the algorithm.

As a result of studies described in [1], it was found that the standard deviation of errors in estimating the intensity of precipitation can be reduced to 2% of the average value. Moreover, it has been shown that random values of precipitation intensity estimates have normal distribution. Then, as a criterion for changing the set of frame sequences and, therefore, the need to calculate the reduction ratio and the predominant direction of precipitation lines, you can use the change in precipitation intensity by more than 3σ, i.e. approximately 5% of the value obtained in the first frame of the current video sequence.

Thirdly, it was possible to reduce the computational complexity of the algorithm by reducing the number of multiplication operations with the coefficients of the filters in the second and third stages of the algorithm.

Matrices used in the second stage have the form (1).

$$S_0 = \begin{vmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{vmatrix},\ S_{30} = \begin{vmatrix} 2 & 2 & 0 \\ 0 & 0 & -1 \\ -1 & -1 & -1 \end{vmatrix},\ S_{45} = \begin{vmatrix} 2 & 1 & 0 \\ 1 & 0 & -1 \\ 0 & -1 & -2 \end{vmatrix},$$
$$S_{60} = \begin{vmatrix} 2 & 0 & -1 \\ 2 & 0 & -1 \\ 0 & -1 & -1 \end{vmatrix},\ S_{90} = \begin{vmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{vmatrix},\ S_{120} = \begin{vmatrix} 1 & 0 & -2 \\ 1 & 0 & -2 \\ 1 & 1 & 0 \end{vmatrix}, \tag{1}$$
$$S_{135} = \begin{vmatrix} 0 & -1 & -2 \\ 1 & 0 & -1 \\ 2 & 1 & 0 \end{vmatrix},\ S_{150} = \begin{vmatrix} 0 & -2 & -2 \\ 1 & 0 & 0 \\ 1 & 1 & 1 \end{vmatrix}.$$

The matrices used in the third stage are (2).

$$H_0 = \begin{vmatrix} -1 & -1 & -1 \\ 1 & 1 & 1 \\ -1 & -1 & -1 \end{vmatrix},\ H_{30} = \begin{vmatrix} -1 & -1 & 1 \\ 1 & 1 & -1 \\ -1 & -1 & -1 \end{vmatrix},\ H_{45} = \begin{vmatrix} -1 & -1 & 1 \\ -1 & 1 & -1 \\ 1 & -1 & -1 \end{vmatrix},$$
$$H_{60} = \begin{vmatrix} -1 & 1 & -1 \\ -1 & 1 & -1 \\ 1 & -1 & -1 \end{vmatrix},\ H_{90} = \begin{vmatrix} -1 & 1 & -1 \\ -1 & 1 & -1 \\ -1 & 1 & -1 \end{vmatrix},\ H_{120} = \begin{vmatrix} -1 & 1 & -1 \\ -1 & 1 & -1 \\ -1 & -1 & 1 \end{vmatrix}, \tag{2}$$
$$H_{135} = \begin{vmatrix} 1 & -1 & -1 \\ -1 & 1 & -1 \\ -1 & -1 & 1 \end{vmatrix},\ H_{150} = \begin{vmatrix} 1 & -1 & -1 \\ -1 & 1 & 1 \\ -1 & -1 & -1 \end{vmatrix}.$$

At these stages, the coefficients of the filters have absolute values of 1 and 2. Multiplication by these coefficients can be easily replaced with the use of pixel brightness values (for the coefficient 1) and a shift of pixel brightness values by one bit (for the coefficient 2). These operations have significantly less computational complexity.

3 Research results

By studying the sequences of video frames of various sizes, which contain precipitations in the form of rain with different intensity, it has been established that reducing the image size by a pre-calculated number of times increases the running time of the algorithm by 7-10%. At the same time, the omission of the first stage of the algorithm, which consists in calculating the preferential direction of the precipitation lines, makes it possible to reduce the operation time of the algorithm by 40-50% of the original, since at this stage, convolution is performed with each of the weight matrices (3) and the search for the module and direction of the gradient $\nabla_I(i,j)$ of the image brightness function $I(i,j)$ for each pixel by formulas (4) and (5).

$$S_x = \begin{vmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{vmatrix}, \ S_y = \begin{vmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{vmatrix}. \tag{3}$$

$$\left|\nabla_I(i,j)\right| = \sqrt{\left(\frac{\partial I(i,j)}{\partial i}\right)^2 + \left(\frac{\partial I(i,j)}{\partial j}\right)^2}, \tag{4}$$

$$\arg\left(\nabla_I(i,j)\right) = arctg\left(\frac{\partial I(i,j)}{\partial i} / \frac{\partial I(i,j)}{\partial j}\right). \tag{5}$$

Reducing the number of multiplication operations in the second and third stages of the algorithm reduces the running time of the algorithm by 35-40% of the initial execution time.

Thus, the total computational complexity of the algorithm is reduced, which ensures its implementation in real time.

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