Mathematical Recognition Problems of Particle Flow Characteristics by Video Sequence Images

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Abstract—The paper is devoted to recognition methods of similar moving particles combined in laminar flow. It is important to obtain data about intensity, velocity and density changes of visible traffic flow areas on image. Video stream from the camera with a fixed angle is received. Algorithms allows to determine the semantics of the image is proposed.

In this paper the problem of optimal placement of virtual detectors, definition of flow characteristics and automatic control of flow behavior at the crossroads is considered.

We present an effective algorithm for the solution of these problems.

Keywords: image processing, virtual detectors, multidimensional signal, laminar flow, variation of function, flow characteristics

1. Introduction

We have a sequence of video frames, that were made by using usual cameras with frequency about 25 frames per second. Camera has constant angle and can fix certain particles movement. Particles are identified by eye, their movements can be described by laminar flows.

Laminar flow is a stream of particles without mixing and ripple.

In this case, there are no abrupt changes in the rate, regarded as a vector, either in magnitude or direction. In contrast to laminar flow, turbulent flow involves disordered unsteady flow with vigorous stirring. The classical model of the flow is the Navier-Stokes equations with Reynolds \( R_e \) parameter, transition through which corresponds as a model of transition from laminar to turbulent flow.

Laminar flow properties is used to create algorithms for image processing and recognition. These methods can be applied, for example, into intelligent processing of video streams of pedestrians, shoal of fishes, vehicles, cells under a microscope (Fig.1, 2), etc.

Most easily to get video of traffic flows, so we will use this type of particles to illustrate the algorithms of video-processing.

2. Image Depth

The basic notion of semantic image analysis is the depth. Fig.3 (a) shows a laminar flow of vehicles on frontal view from the top. This image has constant depth, so processing using the uniform partition Fig.3 (b).

3. Grid partition for image with nonconstant depth

Flow characteristics performed by video sequence from the fixed angle in the case of nonconstant image depth (Fig.4). The image, obtained by the decomposition of the
grid, is imposed on the frames, parameters of which correspond to an equal-area. Average intensity of the color in each cell is fixed.

\[ \begin{align*}
    aq^n &= b, \quad q = \left( \frac{b}{a} \right)^{\frac{1}{n}} \\
    H &= h_1 + h_2 + \ldots + h_n = h_1 + qh_1 + \ldots + q^n h_1 \\
    h_1 &= \frac{1 - q^n}{1 - q} H \\
    y_{k+1} &= y_k - h_1 q^k, \quad k = 0, \ldots, n - 1.
\end{align*} \]

Fig. 5: Trapezoid (a) and close cells of partition (b)

4. Multidimensional signal from field of detectors

If \((i, j)\) is number of grid cell (Fig. 5, b), we fix the average value of color intensity on the cell \(f_{i,j}\). For each \(i\) and \(j\) the variation of function is calculated:

\[ Var_N^N(f_{i,j}) = \sum_{k=0}^{N} |f_{i,j}(k + 1) - f_{i,j}(k)|. \]

Then we get mapping of grey scale:

\[ [\min_{i,j} \{Var_N^N(f_{i,j})\}, \max_{i,j} \{Var_N^N(f_{i,j})\}] \rightarrow [0, 255]. \]

Thus, we get a signal from any detectors on the field. Consider some of cells on the grid partition on image with various depth, these detectors denote A and B (fig.7). Fig.8 shows the signals from detector A (a) and detector B (b) respectively.

If signal from virtual detector is about to constant, we determine it as a noise (Fig.9). Field of detectors generate the multidimensional signal of the video sequence.

5. Recovery of trajectory bundles and estimation of flow intensity and density

The algorithms of video analysis for density and intensity evaluations of laminar flow are developed. Every noticeable peak of signal is equal to fix one of particles.
So let function \( U(t, x, y) \) be a value of color intensity on the field of detectors.

\[
\frac{dU}{dt} = U((k + 1)\Delta t, x, y) - U(k\Delta t, x, y) = \Delta U_t(t, x, y)
\]

Let consider the second difference

\[
\Delta^2 t U = U((k + 2)\Delta t, x, y) - 2U((k + 1)\Delta t, x, y) + U(k\Delta t, x, y)
\]  

(7)

By changing the parameters of the trapezoid: number sensors on the horizontal and vertical vertices of the trapezoid, we can achieve the high accuracy of evaluation, carry out various flows video and a lot of points of view.

6. Optimal placement of detectors

Analyzing the trajectory we solve the problem of optimal placement of detectors.

For identifying moving cluster joined to nearby cells width signs of movement.

Recognition parameters determine recognition quality. We carried out empirical estimations in the fields of bundles detection, lanes detection and road network recovery.

This method can be used for research of the changeable modes of flow. For example the flows on the crossroads we can estimate the mode time by video.

Analyzed specially constructed field of virtual detectors is a discrete function of two variables. Formulated algorithmically accurate decision rules that allow automatically to recover the network, the carriers of these flows and determine the behavior of flows. In particular, the most important problem is to recovery the matrix of flows mixing in the nodes of a planar graph as a function of time (Fig.12).

This information is necessary for an adequate model of the flow dynamics in complex physical networks with saturation and prevent congestion and also for the automatic identification of sources and sinks of flows on these networks.
7. Conclusion & Future work

Experimental studies are conducted on the basis of the mobile laboratory of its own design, equipped with a special system of monitoring and processing on the computer and smartphones using the SSSR-traffic system [10].

The considered approach allows to quantify the measure mixing area of turbulence for different configurations of the flow support and optimize the movement by on-line control.

As next goal we investigate a transition from a laminar flow to a turbulent one. This process for traffic flow is reflected in lane change of vehicles. In the further we plan to apply the algorithms using the field detectors for the estimation of number of lane change of vehicles by video sequence images.

References