Rectified Trajectory Analysis based Abnormal Loitering Detection for Video Surveillance

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Abstract—Trajectory analysis for detection of abnormal loitering has attracted significant research interest in recent years. We present a new approach for abnormal loitering detection using trajectory analysis. Trajectory Direction History Analysis method is proposed to detect abnormal loitering and Inverse Perspective Mapping (IPM) is presented to resolve distortion of trajectory direction because of perspective effect. Proposed loitering detection method has shown good performance.

Keywords- Video Surveillance; Abnormal Behavior Detection;

I. INTRODUCTION

Intelligent video surveillance system is to monitor the activity of objects in a video. Visual surveillance has a wide variety of applications such as homeland security, crime prevention, and traffic control and so on. Intelligent video surveillance system should support not only basic object detection and tracking, but also interpret object abnormal behavior pattern finally. Trajectory is one of the popular features in abnormal behavior detection on surveillance system. So, abnormal trajectory analysis is main issue in surveillance system in recent years.

So far, many trajectory analysis researches are doing for abnormal behavior detection. Basically, object trajectory should be generated by object detection and tracking for motion pattern modeling and abnormal behavior. Using the trajectories, motion pattern modeling is defined. After modeling of trajectories, abnormal behavior detection is preceded.

Analysis and modeling of motion patterns for surveillance scenes have been studied by several researchers. In [1] [2], trajectories are clustered by the similarity of spatial information. In [3], use velocity and aspect ratio to classify different tracks into vehicle or person. They utilized a Bayesian classifier for this task and an HMM model to capture common events in the scene. Makris [4] have presented a method in which different regions of the scene are labeled as entry/exit zones, junctions, paths and stop zones. In [5], they proposed a single Kernel Density Estimation (KDE) model for the whole scene, which requires to save all training data. Junejo [6] apply graph cuts to cluster trajectories using the Hausdorff distance to compare different trajectories and calculate the edge weights of the similarity matrix. [7][8] learned the transition probability of each pixel moving from the surrounding pixels using kernel density estimation or Gaussian mixture model.

In this paper, we propose Trajectory Direction History Analysis (TDHA) method to detect abnormal loitering, which analysis direction of trajectory. And, we also propose Inverse Perspective Mapping (IPM) to resolve distortion of trajectory direction because of perspective effect. Proposed method has shown good performance in detecting of abnormal loitering.

Fig. 1 shows normal trajectory and abnormal trajectory.

Figure 1. Trajectories(normal(a), abnormal(b))

This paper proposes Trajectory Direction History Analysis (TDHA) method for detection of abnormal behavior like loitering. In general, normal trajectory makes direction history which has small direction variation. But, abnormal behavior makes direction history that has large direction variation like Zigzag and meandering. Using this point, abnormal loitering can be detected by analyzing direction history.

Section II describe how TDHA works, and section III describe IPM processing. We show test results in Section IV. Finally, we conclude section V.
II. TRAJECTORY DIRECTION HISTORY ANALYSIS

In this paper, we use codebook [9] to detect moving object. Center point of Object is used for object location in image. Trajectory is composed of object location point (x, y).

\[ T_i = \{ p_1, p_2, ..., p_n \}, \quad p_i = (x, y) \quad (1) \]

At first, trajectory is regenerated by Representative Point (RP). RP’s are selected by equation (2), which means that the distance between \( p_1(x_1, y_1) \) and \( p_2(x_2, y_2) \) is bigger than threshold.

\[
\text{dist} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \quad \text{if} \quad \text{dist} \geq \text{Th} \quad \text{then} \quad \text{RP} \\
T^1_i = \{ p_1, p_2, ..., p_k \}, \quad p_i = (x, y)
\]

Fig.2 shows trajectory smoothing result of input trajectory.

Fig.2. Trajectory smoothing

Adjacent two points \( p_1(x_1, y_1), p_2(x_2, y_2) \) are calculated by equation (3) to analysis direction history of trajectory. Then, new trajectory \( T^2_i \) is generated, which is composed of following vectors.

\[
v = (v_x, v_y), \quad v_x = (x_1 - x_2), \quad v_y = (y_1 - y_2) \\
T^2_i = \{ v_1, v_2, ..., v_{k-1} \}
\]

After that, Overall direction history of trajectory \( T^2_i \) is generated. Direction between two vectors is calculated for direction history. Equation 4 explains how angle between two vectors is calculated.

\[
v_1 \cdot v_2 = |v_1||v_2|\cos \theta, \quad \cos \theta = \frac{v_1 \cdot v_2}{|v_1||v_2|} \quad (4)
\]

Fig. 3 shows angle between two vectors. Like Fig.3, we can acquire trajectory direction information that trajectory is going.

Fig. 3. Calculate direction angle between two vectors

General and normal trajectory will have small direction variations between two vectors. But abnormal trajectory will have irregular and large direction variations.

Next, overall directions history of trajectory is analyzed like following TDHA algorithm.

**Algorithm**

Calculate representative trajectory \( T^1_i \) 

Calculate vector trajectory \( T^2_i \)  
Reference Vector (RV) = \( V_1 \)  
Count = 0;  
For (\( i = 2 \); \( i < k;\) \( i++ \))  
  \( \text{Calculate theta between RV and } V_i \)  
  if( \( \text{theta} \geq \text{Th} \))  
    Increase count;  
  Reference vector(RV) = \( V_i \);

In TDHA algorithm, first vector as reference vector in trajectory is compared with other vectors until the angle between two vectors is bigger than threshold. When it is bigger than threshold, new reference vector is assigned and the angle between reference vector and other vector is checked on and on. If the total number of suspicious direction changes of trajectory is bigger than arbitrary threshold then, the trajectory is regarded as abnormal loitering. Trajectory like Zigzag and meandering makes many direction changes.

III. TRAJECTORY RETIFICATION

Generally, CCTV images have perspective effect problem. So, measuring the spatial distance and direction angle of trajectory can cause errors due to projection distortion.

In this paper, we use Inverse Perspective Mapping (IPM) [10] to remove perspective effect. IPM transform perspective view image to top-view image.

Two coordinate in IPM are defined like following: (Fig. 5(a)).

- \( W = \{ (x, y, z) \} \in \mathbb{E}^3 : \text{representing the 3-D world space (world-coordinate), where the real world is defined.} \)
- \( I = \{ (u, v) \} \in \mathbb{E}^2 : \text{representing the 2-D image space (screen-coordinate), where the 3-D scene is projected.} \)

IPM procedure resamples the incoming, remapping each pixel toward a different position and producing a new two-dimensional array of pixels. The image acquired by the camera belongs to the \( I \) space, while the remapped image is defined as the \( z=0 \) plane of the \( W \) space. The remapping process projects the acquired image onto the \( z=0 \) plane of the 3-D world space \( W \).

In order to generate a 2-D view of a 3-D scene (\( I \rightarrow W \) mapping), the following parameters are defined.
\[ \begin{align*}
    x(u,v) &= h \times \cot \left[ (\alpha - \omega) + \frac{2\alpha}{n-1} \right] \\
    y(u,v) &= h \times \cot \left[ (\alpha - \omega) + \frac{2\alpha}{m-1} \right] \\
    z(u,v) &= 0
\end{align*} \]

Equation (5) returns the coordinates \((x, y, 0)\) of the corresponding point in the \(W\) space (3-D space of \(z=0\)).

Remapping process \((W \rightarrow I\) Mapping) defined in (6) removes the prospective effect and recovers the texture of the \(z=0\) plane of the \(W\) space.

It is implemented scanning the array of pixels of coordinates \((x, y, 0)\) which form the remapped image.

\[
\begin{align*}
    u(x,y,0) &= \frac{\theta(x,y,0) - (\alpha - \omega)}{2\omega} \\
    v(x,y,0) &= \frac{\gamma(x,y,0) - (\beta - \omega)}{2\omega} \\
    \theta(x,y,0) &= \tan^{-1}(\frac{h}{x^2+y^2}), \gamma(x,y,0) = \tan^{-1}(\frac{k}{n})
\end{align*} \]

Fig. 4 shows the original and remapped images. It shows that right image (IPM transformed image) provides more accurate trajectory direction information than left image with perspective effect.

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IV. EXPERIMENTAL RESULTS

We implemented the proposed method using Visual Studio on the Windows 7 and tested on Core 2 Duo CPU 3GHz PC. And it runs at less 50ms.

The performance of the proposed method was tested with real input trajectories and artificial input trajectories. Real input trajectories are generated from real human tracking of CCTV video. Artificial input trajectories are generated by manual mouse movement on the image.

The test results are like Fig. 6 and Fig. 7. Normal trajectories (Fig.(a)) and abnormal trajectories(Fig.6(b)) are detected well. We can know that the abnormal behavior like Zigzag and meandering have many direction changes like Fig.6 and Fig.7.

V. CONCLUSIONS

In this paper, we have presented Trajectory Direction History Analysis (TDHA) method to detect abnormal loitering, which analysis direction changes of trajectory.

And, we also proposed Inverse Perspective Mapping (IPM) to resolve distortion of trajectory direction because of perspective effect. Proposed method has shown good performance in detecting of abnormal loitering.

In the future, more detailed analysis of direction change of trajectory would be interesting and researching.

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