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Outlier detection from vehicle trajectories to discover roaming events

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ABSTRACT

Roaming, referring to the behavior of repeated observation of intended crime scenes before committing crimes, is a suspicious pattern often mentioned by experienced police investigators, but still remains a vague concept which needs to be well realized in video surveillance systems. This work first describes the scenario of roaming behaviors related to planned crimes, and then derives formal specifications for detecting suspicious roaming events from vehicle trajectories. Consequently, algorithms are designed for rapidly sorting out potential outliers and thoroughly examining their suspicious intention through circling activities, relative driving speed and time dispersion. Roaming trajectories and relevant trajectories are finally grouped into events and appropriately ranked. Furthermore, preliminary experiments and illustrative examples on synthetic data demonstrate the feasibility of our methods. The proposed approach enhances conventional vehicle plate analysis so that it becomes capable of discovering complex criminal behaviors and hence increasing investigation performance and decision quality.

1. Introduction

As surveillance cameras become prevalent in all kinds of public places like parking lots, highways and building entrances, the automatic number plate recognition (ANPR) system is enjoying advanced applications, including traffic flow detection and road surveillance. From the aspect of policing, ANPR assists police on entrance control, speeding detection and in advanced crime investigations involving vehicle theft or property crimes. For example, Brown et al. [5] introduce an intelligence-led policing system capable of providing daily real-time information through analyzing past vehicle crime patterns and real-time traffic information for the police to become cognizant of suspects in high-risk areas. The potential of implementing ANPR on crime investigations is also discussed in [20].

Suspicious vehicle behavior patterns such as stagnation, convoy and roaming are of interest to prevent premeditated large-scale robberies, gang events and even homicide. In particular, *roaming*, which refers to behaviors similar to wandering or loitering, is a complicated pattern and is common in crime events because of the intention to repeatedly observe planned crime scenes before committing crimes. Although some commercial products claim the capability of detecting these suspicious behaviors, large manual specifications of monitoring areas are usually required. Moreover, they detect roaming simply based on repeat appearance or rigid loops, hence often resulting in large numbers of false alarms.

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Trajectory outlier detection is studied extensively to identify abnormal moving objects. Herein, a trajectory refers to the passing route of one vehicle within a continuous time period. Differing from normal mining methods which consider only one numerical parameter in similarity measurement, multiple parameters are adopted in this field. For example, spatial (location and angle) and temporal similarities are considered in detection of traffic congestion and abnormal traffic flow [6,36]. In [37], where structure similarity measurement is proposed, even speed and duration are taken into consideration in regard to similarity. However, those studies were not designed specifically to detect roaming trajectories relevant to crime events. Moreover, in detecting and finding roaming behaviors with relevant events, the similarity measurements are not shape-based but intention-based, which leads to a vague definition and may not be appropriate for applying common trajectory mining or outlier detection methods. Besides, due to the varied road network, some seemly roaming behavior could originate from the restriction of artery design; for example, one way, traffic circle and highway ramps are places where driver must execute redundant direction change; some other cases are simply being lost. All of these factors increase the possibility of false alarms and constitute an impractical system. In addition, in order to assist police investigations when proposing abnormal trajectories related to one event, it is also necessary to rank the level of suspicion of these events by convincible criteria, which is also a subject that has not been discussed thoroughly.

This work proposes a comprehensive approach to detecting suspicious roaming trajectories, grouping relevant trajectories to roaming events and finally ranking discovered events. Regarding the scenario of committing a crime with prior observations, it is obvious that the premeditated crime scenes are among roaming trajectories. Under this condition, the concept of *feature regions*, i.e., the regions where roaming vehicles observe and are deemed as premeditated crime scenes, is proposed as the similarity measurement to identify trajectories relevant to similar events. In regard to suspicious behaviors like circling at relatively slow speed and in regions with higher levels of importance (near a bank for example), regions of interest can be identified. In addition, since roaming behaviors involve actions such as one or more circling, roaming trajectories produce more redundant travel distance than other normal trajectories. For example, a normal trajectory with the purpose of finance intention will go straight from home to bank, but roaming trajectories with the purpose of observing a bank will probably involve circling around the bank more than one time, thereby creating redundant total distance. This characteristic is used as a threshold to preliminarily judge possible roaming trajectories on shape aspect to increase detection efficiency. Lastly, a ranking mechanism is proposed to exhibit top detected abnormal events according to degree of suspicion. The experiment on synthetic data on a real road map shows that the proposed approach obtained valuable results, compared with a widely adopted outlier detection approach (DBSCAN as described in Section 2.3).

The remainder of this paper is organized as follows. Section 2 reviews related literature. Section 3 then describes a scenario of roaming events and derives the assumptions about suspicious roaming events. Section 4 introduces the proposed method for detecting roaming trajectories and events. Section 5 presents the results of an evaluation on synthetic data. Conclusions are finally drawn in Section 6, and recommendations for future research are suggested.

2. Related work

2.1. Plate analysis for crime investigation and detection

Recently, ANPR has proven successful in enabling the rapid recovery, matching, identification and tracking of vehicles of interest, thus allowing police to take immediate action [16,20]. Besides, many intelligence-led policing projects, such as Operation Gallant in England, analyze the past data on property crime and real-time traffic situations daily to provide timely information like hotspots of vehicle crimes, prolific vehicle crime offenders and patterns of offending as reference, in addition to alerting civilians by mail or text message around the warning area; this has had a significant effect on crime prevention [15,25]. Kaza et al. [19] also propose a mutual information-based association analysis to discover and identify suspect vehicles that may be involved in criminal activity. Besides vehicle information, Xue and Brown [35] analyze the spatial behavior of criminal incidents to predict future criminal locations. However, most of the studies only focus on how plate analysis can generate varied statistical data to enhance investigation and even prevent traffic violations and property crimes while enhancing homeland security.

2.2. Trajectory pattern and feature extraction

Generally, the discretization of spatial and temporal information is essential to the attribute extraction for trajectory analysis. Various spatial distance-based similarity measures are proposed, such as the Euclidean distance, the Manhattan distance, the shortest-route distance and the DTW (Dynamic Time Warping) distance [24,28,32]. Particularly, the Manhattan distance is widely used in practical crime geospatial mapping and modeling for its computational efficiency and satisfactory accuracy [7].

Spatial and temporal features of trajectories are usually considered together. For example, time duration is combined with spatial information and forms minimal bounding boxes (MBBs) in [36]; the overlapped area of MBBs is intuitively used for similarity measurement. Besides, Kang and Yong [18] discover ST-pattern by the use of the DP (Douglas-Peucker) algorithm for line simplification, and give a proper segmentation interval for both spatial and temporal dimensions. Moreover, Lee et al. [21] propose a graph-based algorithm to discover frequent spatial–temporal trajectory patterns. In addition, some