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(54) **Title:** SCENE ACTIVITY ANALYSIS USING STATISTICAL AND SEMANTIC FEATURE LEARNED FROM OBJECT TRAJECTORY DATA

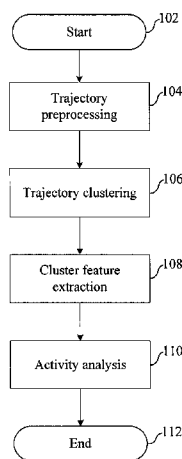


FIG. 1

(57) **Abstract:** Trajectory information of objects appearing in a scene can be used to cluster trajectories into groups of trajectories according to each trajectory's relative distance between each other for scene activity analysis. By doing so, a database of trajectory data can be maintained that includes the trajectories to be clustered into trajectory groups. This database can be used to train a clustering system, and with extracted statistical features of resultant trajectory groups a new trajectory can be analyzed to determine whether the new trajectory is normal or abnormal. Embodiments described herein, can be used to determine whether a video scene is normal or abnormal. In the event that the new trajectory is identified as normal the new trajectory can be annotated with the extracted semantic data. In the event that the new trajectory is determined to be abnormal a user can be notified that an abnormal behavior has occurred.



SCENE ACTIVITY ANALYSIS USING STATISTICAL AND SEMANTIC FEATURES LEARNT FROM OBJECT TRAJECTORY DATA

BACKGROUND

[0001] Increasingly, many aspects of our lives are monitored and recorded. For example,
5 video surveillance is prevalent, recording scenes for news, general information, and security
purposes. Security cameras record visual information of desired locations such as banks,
storefronts, automatic teller machines, businesses, roadways, parks, etc.

[0002] Typical scene activity analysis methods require operators to specify the events of
interest using details such as location, time and event types. Not only is this laborious in case
10 of a large number of surveillance cameras, but also it may lose important events that were
never discovered before.

BRIEF SUMMARY

[0003] A method for providing scene activity analysis and/or trajectory information
summarization about a video scene is disclosed according to some embodiments of the
15 invention. Such a method can include obtaining video scene metadata that includes
information regarding trajectories for a plurality of objects moving through the video scene.
Each of the plurality of trajectories can be clustered into trajectory groups according to their
relative distance from each other and each trajectory in the plurality of trajectories can be
classified as a normal trajectory or an abnormal trajectory based at least in part on the
20 clustering. Statistical features can be extracted about trajectory groups, and they can be used
to classify a trajectory as a normal or an abnormal trajectory. Semantic data can be extracted
for each trajectory group or for each normal trajectory, and each normal trajectory can be
annotated with the semantic data, for example, in metadata.

[0004] In some embodiments, the clustering can include a number of clustering iterations
25 using a plurality of different distance measures. In some embodiments, the distance measure
can include a minimum distance between trajectories, a maximum distance between
trajectories, or an average distance between trajectories. In some embodiments, statistical
features of a trajectory group can include: average and standard deviation of object height,
object width, object size, object speed, object appearance color, object shape, trajectory
30 length, trajectory duration, moving direction probability, spatial occurrence probably,
temporal occurrence probably, to name a few. Similarities between statistical features can be

used for clustering. That is, trajectories with similar statistical features can be clustered together. In some embodiments, the semantic data includes entry zones, exit zones, representative trajectories, pivotal points and directions of trajectory patterns, and/or crossing zones between different trajectory patterns. In some embodiments, a normal trajectory can be a trajectory with statistical features similar to other trajectories within a group. In some 5 embodiments, an abnormal trajectory is a trajectory that is unassociated with any group of trajectories.

[0005] A computer program product residing on a non-transitory processor-readable medium for providing trajectory information about a video scene is also disclosed. The 10 computer readable medium includes instructions to: cluster each of a number of trajectories into trajectory groups according to their relative distance from each other; classify each trajectory as a normal trajectory or an abnormal trajectory based at least in part on the clustering; extract semantic data from each trajectory group or each normal trajectory; and annotate each normal trajectory with the semantic data. In some embodiments, the 15 instructions can cause the processor to cluster each of plurality of trajectories into trajectory groups comprise instructions configured to cause the processor to iteratively cluster the plurality of trajectories using different distance measures. In some embodiments, in the event a trajectory is classified as a normal trajectory further comprising annotating a normal trajectory based on the trajectories association with a classified group of trajectories.

20 [0006] A trajectory analysis system that includes an input, memory and a processor is also disclosed. The input can be configured to receive video scene metadata that includes information regarding the trajectories of objects as the objects move within the video scene. The processing unit can be communicatively coupled to the input and the memory. And the processor can be configured to cluster each trajectory into a trajectory group according to the 25 trajectory's relative distance from previously analyzed trajectories; identify each trajectory as a normal trajectory or an abnormal trajectory based at least in part on the clustering; and annotate each normal trajectory as a normal trajectory or an abnormal trajectory.

[0007] In some embodiments, the processing unit can be configured to extract semantic data from each trajectory group or each normal trajectory and annotate the normal trajectory 30 with the semantic data. The trajectory analysis system can also include a user interface and the processing unit is configured to notify the user through the user interface in the event a

trajectory is an abnormal trajectory. The trajectory analysis system can also include a camera.

5 [0008] A method for determining abnormal behavior in a video scene is also provide. The method can include creating a database of normal trajectories from video data of a scene that includes a plurality of objects moving through the scene along a trajectory; identify a new trajectory within the video scene; determine whether the new trajectory is a normal trajectory; and in the event the new trajectory is not a normal trajectory, notifying a user. A normal trajectory comprises a trajectory that is clustered with a plurality of previous trajectories within the video scene. In some embodiments, a normal trajectory comprises a trajectory
10 whose distance is near a plurality of previous trajectories within a group in terms of statistical feature similarities.

[0009] In some embodiments, the creating a database of normal trajectories can include clustering each trajectory into a trajectory group according to its relative distance from other trajectories; classifying each trajectory as a normal trajectory or an abnormal trajectory based
15 at least in part on the clustering; and saving the results of the classification in a database. In some embodiments, the determining whether the new trajectory is a normal trajectory comprises determining the relative distance in terms of statistical feature similarities between the new trajectory and one or more of the normal trajectories stored within the database.

[0010] A trajectory analysis system is also provided that includes an input, a user interface,
20 memory, and a processing unit. The input can be configured to receive video scene metadata that includes information regarding the trajectories of objects as the objects move within the video scene. The memory can be configured to store normal trajectories from video data of a scene that includes a plurality of objects moving through the scene along a trajectory, wherein a normal trajectory comprises a trajectory that is clustered with a plurality of
25 previous trajectories within the video scene. The processing unit can be communicatively coupled to the input and the memory. And the processing unit can be configured to: identify a new trajectory within the video scene; determine whether the new trajectory is a normal trajectory; and in the event the new trajectory is not a normal trajectory, notify a user through the user interface.

30 [0011] According to some embodiments, a normal trajectory is identified as a normal trajectory when the new trajectory is near a plurality of previous trajectories in term of a statistical feature derived score. In some embodiments, the new trajectory is identified as

being near another trajectory based on the relative distance from the new trajectory and the plurality of trajectories. The relative distance can be a minimum distance between trajectories, a maximum distance between trajectories, and/or an average distance between trajectories. In some embodiments, the new trajectory is identified as being near another trajectory not only based on the relative distance from the new trajectory and the plurality of trajectories, but also taking into account their similarity in moving direction, speed, or appearing time, etc.

[0012] In some embodiments of the invention trajectory information can be used to cluster trajectories into groups of trajectories according to each trajectory's relative distance between each other. By doing so, a database of trajectory data can be maintained that includes the trajectories organized into trajectory groups. This database can be used to train a system to identify a trajectory or a group of trajectories as normal and/or abnormal. From this information a new trajectory can be analyzed to determine whether the new trajectory is normal or abnormal. Embodiments described herein, can be used to determine whether a video scene is normal or abnormal. In the event that the new trajectory is determined to be abnormal a user can be notified that an abnormal behavior has occurred.

[0013] Items and/or techniques described herein may provide one or more of the following capabilities, and/or other capabilities not mentioned. Items of greater interest in a captured image, e.g., of a video, can be displayed with higher resolution than items of lesser interest. The items of greater interest and the items of lesser interest can be displayed on different displays, or in a single display. A viewer can see items of interest in a display more clearly than other items. Moving objects can be tracked and displayed with higher resolution than stationary or relatively stationary objects. Objects can be displayed with higher resolution in a portion of a display that facilitates viewing with high-resolution portions of a person's eye. Further, it may be possible for an effect noted above to be achieved by means other than that noted, and a noted item/technique may not necessarily yield the noted effect.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The patent or application file contains at least one drawing executed in color. Copies of this patent or patent application publication with color drawing(s) will be provided by the Office upon request and payment of the necessary fee.

[0015] FIG. 1 is a flowchart of an activity summarization process.

[0016] FIG. 2 is a more detailed flowchart of an activity summarization process.

- [0017] FIG. 3A is a five node graph for various trajectories.
- [0018] FIG. 3B shows five sample trajectories.
- [0019] FIG. 4 is a flowchart of a process for clustering trajectories.
- [0020] FIG. 5 is a flowchart of a process for clustering nodes within a group through
5 iterative local node grouping.
- [0021] FIG. 6 is a flowchart of a process for constructing a group of nodes centered at a seed
- [0022] FIG. 7A-7F are scene examples with trajectories superimposed thereon.
- [0023] FIG. 8 is a flowchart of an activity summarization process.
- 10 [0024] FIG. 9 is a functional block diagram of a processing unit.
- [0025] FIG. 10 is a block diagram showing the influential region of various trajectories.

DETAILED DESCRIPTION

[0026] Techniques for analyzing scene activity are disclosed. In some embodiments, techniques can automatically learn normal behaviors of an object moving within in a scene
15 (field of view), and extracts their statistical and semantic features. The learned features can be utilized to identify anomalies while analyzing normal scene behaviors. Using these techniques, there is no need for operators to have prior knowledge about a scene and set event rules as most of current video analytic systems do.

[0027] One objective of activity summarization is to discover the essential patterns of
20 objects' behaviors in a semantically meaningful manner. In some techniques, this can be done by analyzing the trajectory data of moving objects resulted from video analytics algorithm about what, where, when and how the objects appear in the scene. Semantic information can benefit the analysis of objects' activities occurring in a scene in different ways, from low level object detection, to middle level event detection, and to high level
25 activity understanding and abstraction, forensic search, etc. The semantic representation of scene activities can be learned through a data driven clustering method automatically or with minor human interactions if required.

[0028] Given a set of objects' trajectories in terms of their objects, in some embodiments, trajectories can be grouped according to selected features such as spatial location and form

clusters, and then apply the resultant clusters to model their common properties in terms of statistical features and semantic features. With learned statistical features, an object's behavior can be classified into either normal or abnormal activity, and a normal activity can be further annotated by using the semantic features of its belonged cluster.

- 5 [0029] When an object moves from one position to another position within a camera scene, the objects visual representation can be represented by a trajectory. A trajectory includes a sequence of spatial locations in terms of image pixel coordinates visited by the object in order of occurrence. A trajectory can be modeled as

$$T_o = \{(x_i^o, y_i^o, f_i^o) \mid i = i_s^o \dots, i_e^o\}$$

- 10 where (x_i^o, y_i^o) denotes the coordinates in the 2D image of the monitored scene of object, o , and f_i^o denotes a feature of the object at discrete time i , which can range from the object's start time t_s^o to the object's disappearing time t_e^o . For convenience, it can be simplified as the index number of corresponding observation of trajectory T_o , specifically 1 corresponding to the first observation at the starting time, and 2 corresponding to the second, and so on.
- 15 Thus, the trajectory with m observations of object o can be represented as

$$T_o = \{(x_i^o, y_i^o, f_i^o) \mid i = 1 \dots, m\}.$$

Object feature f_i^o may represent a set of features including object moving direction, speed, appearance, object width, object height, etc.

- 20 [0030] Referring to FIG. 1 process 100 for making scene activity summarization and analysis starts at block 102 and includes four generalized blocks. These blocks include trajectory preprocessing 104, normal trajectory clustering 106, cluster feature extraction 108, and activity analysis 110. Process 100 then ends at block 112. Process 100 is, however, an example only and is not limiting. Process 100 can be altered, e.g., by having blocks added, removed, rearranged, combined, and/or performed concurrently.

- 25 [0031] Referring to FIG. 2 process 200 is a more detailed process for scene activity summarization and analysis that includes the shown blocks. Process 200 is, however, an example only and is not limiting. Process 200 can be altered, e.g., by having blocks added, removed, rearranged, combined, and/or performed concurrently. Video analytics of recorded

video scenes can be conducted and the various trajectories of objects within the scenes can be stored in trajectory database 205. These trajectories can be used throughout process 200.

Various techniques can be used to produce the trajectory data. Moreover, the trajectory information can be stored as metadata either in conjunction with the video scene or separate

5 therefrom. Process 200 starts at block 210. At block 215 the trajectory data is used to generate a graph representation of the trajectory data with each node presenting a trajectory and an edge indicating the distance between its two connected nodes (e.g., spatial distance between the two trajectories). At block 220 trajectories can be clustered using a graph partitioning algorithm to split the graph into sub-graphs. For example, the sub-graphs can be
10 made such that nodes within a sub-graph include the nearest neighbors of a seed trajectory that fall into an expected distance range of the seed trajectory according to the statistics of their distributions. Clusters of trajectories are automatically formed based on distance and require no prior knowledge about the number of clusters. The resultant clusters can vary and reflect different natures based on the distance measure used to cluster the graph. Thus, with
15 the same graph based clustering algorithm, different clustering results can be achieved to produce different target goals. This can be done, for example, at run control block 225.

[0032] In some embodiments, three clustering runs can occur. Each of these can involve different parameters related to the definition of distance matrices of graph edges, cluster statistics updating scheme, and/or the handling of leftover trajectories (trajectories that do not
20 belong to any clusters). Runs 1 and 2, for example, can be designed for trajectory selection in the preprocessing stage. Run 3, for example, can be designed for normal trajectories clustering. Each run, for example, can cluster trajectories using a different distance measure. Turning first to run 1. This run can adopt a strict distance measure to group spatially close trajectories seriously and form clusters based on operator input from block 230. For example,
25 run 1 can use the maximum distance between trajectories as the clustering measure. As another example, run 1 can use the mathematical function termed Distance 1, defined below, as the clustering measure. Operator input from block 230 can determine if a cluster and the related constituent trajectories need to be removed at block 235. In some embodiments, run 1 can be skipped, and all collected trajectories can undergo run 2. This can depend on whether
30 operator input is desired.

[0033] Run 2 can be similar to run 1, but with a less strict distance measure. In some embodiments, run 2 can cluster trajectories based on the minimum distance between trajectories. As another example, run 2 can use the mathematical function termed Distance 2,

defined below, as the clustering measure. The results from run 2 can produce clusters that have more compatibility among trajectories. For example, if there are two trajectories such that one of which is part of the other, run 2 can determine that the two runs are very close with each other.

5 [0034] Trajectories passing through run 1 and run 2 are fed into run 3 for further clustering. A third distance measure is defined during run 3 that calculates the average distance of trajectories. This is different than run 1 that uses the maximum distance between trajectories and run 2 that uses the minimum distance between trajectories. Normal activity clusters are formed that indicate a typical pattern of objects' trajectories in the monitored scene. As
10 another example, run 3 can use the mathematical function termed Distance 3, defined below, as the clustering measure.

[0035] Block 240 can determine if all runs (e.g., all three runs, if all three runs are used) have been completed. If so, statistical features about each cluster of trajectories can be extracted at block 245. These statistical features can include, for example, average and
15 standard deviation of object and trajectory features (e.g., object height, object width, object size, object speed, object appearance color, object shape, trajectory length, trajectory duration), direction probability, spatial occurrence probably, temporal occurrence probably, etc. And at block 250, semantic features can be extracted. These semantic features can include, for example, representative trajectories, entry zones, exit zones, crossing zones
20 between different trajectory patterns, pivotal points and directions of trajectory patterns, etc.

[0036] At block 255 each trajectory can be classified as normal activity associated with a resulted cluster or an abnormal activity that does not belong to any clusters. This classification, for example, can use the statistical features extracted at block 245. In some
25 embodiments, the identification of a trajectory as an outlier may be a cause for concern. For instance, in secure locations such as airports or military bases, abnormal behavior can be related with an abnormal trajectory. As such, a video camera can record scenes from such locations and the embodiments described herein can classify an activity as an abnormal activity. If such an activity is found, the authorities may be alerted, for example, by sounding an alarm, or the like. If it is determined, at block 260, that a trajectory includes normal
30 activity, then the trajectory can be annotated using semantic features at block 265. Regardless of the determination made at block 260, the results can be logged into a data storage 265 and process 200 can end at block 270.

[0037] In some embodiments, trajectories of different objects can be grouped using a distance measure as a clustering criterion. For example, the spatial distance between a pair of trajectories can be used. Depending on the target objective, a distance measure can be defined for the discrete representation of a trajectory.

5 [0038] Assume the training data set has t trajectories, denoted by $T = \{T_o | o = 1, \dots, t\}$. Let $d_{ab} = d(T_a, T_b)$ be the distance between T_a and T_b . The training trajectory data set can be represented as an undirected graph, $G = (T, E)$ where T is the set of trajectory nodes with node o representing T_o and E is a set of edges with the edge E_{ab} linking node a and node b and its weight d_{ab} representing the distance of the two connected nodes.

10 [0039] With training trajectory data available, the distances can be represented in a graphical form. An example of a five-node graph is provided in FIG. 3A that corresponds to the five sample trajectories in FIG. 3B. When clustering them as groups according to their spatial proximity, it is reasonable to separate them into two groups by observing FIG. 3B. This can also be accomplished by partitioning the equivalent graph in FIG. 3A, where T_1, T_2
 15 and T_3 are near together and can form a group while T_4 and T_5 are near together and can form the other group since each group has small intra distance among its constituent trajectory nodes while the inter distance between the two groups are large. With a large number of training trajectories, it can be challenging to place graphs into sub-graphs.

[0040] Different trajectories may have different number of observations, and measuring the
 20 distance of a pair of them can be done by normalizing them first into a unified length, i.e., having a same number of observations via such techniques as sampling or interpolation, and then applying a traditional distance metric to calculate the distance. An alternative way is to adopt metrics that can calculate the distance between two different-size sets of points, such as Hausdorff distance. As noted above, three different clustering runs were described in relation
 25 to FIG. 2, where each run used a different distance to achieve different goals. Given two

trajectories, $T_a = \{(x_i^a, y_i^a, f_i^a) | i = 0, \dots, m\}$ for object a and

$T_b = \{(x_j^b, y_j^b, f_j^b) | j = 0, \dots, n\}$ for object b , three distance metrics are defined below:

[0041] Distance 1: $d_{ab}^{\max} = \max(d(T_a, T_b), d(T_b, T_a))$, where

$$d(T_a, T_b) = \max_{i \in \{1, \dots, m\}} \left(\min_{j \in \{1, \dots, n\}} \left(\left\| (x_i^a - x_j^b), (y_i^a - y_j^b) \right\| \right) \right)$$

is the directed distance from T_a to T_b and $\left\| \left(x_i^a - x_j^b \right), \left(y_i^a - y_j^b \right) \right\|$ may take either city block distance or Euclidean distance between points $\left(x_i^a, y_i^a \right)$ and $\left(x_j^b, y_j^b \right)$. Similarly $d(T_b, T_a)$ is the directed distance from T_b to T_a . The basic concept behind the directed distance metric $d(T_a, T_b)$ is that for each of observations of T_a , find the minimum of all its distances to every observation of T_b and then take the maximum as the directed distance from T_a to T_b . Finally, d_{ab}^{\max} takes the larger one of $d(T_a, T_b)$ and $d(T_b, T_a)$ as the undirected distance of the two considered trajectories.

[0042] Distance 2: $d_{ab}^{\min} = \min(d(T_a, T_b), d(T_b, T_a))$, where d_{ab}^{\min} takes the smaller one of $d(T_a, T_b)$ and $d(T_b, T_a)$.

10 **[0043]** Distance 3: $d_{ab}^{\text{avg}} = \max(d'(T_a, T_b), d'(T_b, T_a))$, where

$$d'(T_a, T_b) = \frac{1}{m} \sum_{i=1}^m \min_{j=1}^{n-1} \left(d(x_i^a, y_i^a, L(x_j^b, y_j^b, x_{j+1}^b, y_{j+1}^b)) \right),$$

and $d(x_i^a, y_i^a, L(x_j^b, y_j^b, x_{j+1}^b, y_{j+1}^b))$ is the perpendicular distance from point $\left(x_i^a, y_i^a \right)$ to line segment $L(x_j^b, y_j^b, x_{j+1}^b, y_{j+1}^b)$ connecting $\left(x_j^b, y_j^b \right)$ and $\left(x_{j+1}^b, y_{j+1}^b \right)$ if the base of the perpendicular dropped from $\left(x_i^a, y_i^a \right)$ to $L(x_j^b, y_j^b, x_{j+1}^b, y_{j+1}^b)$ is located within

15 $L(x_j^b, y_j^b, x_{j+1}^b, y_{j+1}^b)$; otherwise, $d\left(x_i^a, y_i^a, L(x_j^b, y_j^b, x_{j+1}^b, y_{j+1}^b)\right)$ takes the smaller of the two distances from $\left(x_i^a, y_i^a \right)$ to $\left(x_j^b, y_j^b \right)$ and $\left(x_{j+1}^b, y_{j+1}^b \right)$. Different from distance 1, distance 3 first calculates the average of the minimum distance among all the perpendicular distances from every observation of one trajectory to the other trajectory, and then pick the maximum.

20 **[0044]** In some embodiments, two parameters can be used to control the clustering process: a parameter update-mode and a removal-flag. Parameter update-mode controls how to update the distance statistics of a cluster as a clustering process proceeds, and it can have two options: weighting average and direct arithmetic average. Parameter removal-flag can be used to facilitate the outlier trajectory removal. If the removal-flag is enabled, then when the

clustering process is terminated all the remaining un-clustered trajectories are treated as outliers and thus removed. Such trajectories are not considered in further clustering processes. Otherwise, all the remaining un-clustered trajectories are treated as an independent separate cluster and are further processed in next level clustering.

5 [0045] Referring to FIG. 4 with further references to Figs. 1-3, process 400 for clustering trajectories that includes the blocks shown. Process 400 is, however, an example only and is not limiting. Process 400 can be altered, e.g., by having blocks added, removed, rearranged, combined, and/or performed concurrently. Process 400 starts at block 402. At block 404 a distance matrix can be created. The distance matrix can include the weights of the edges in
10 the graph representation shown in FIG. 3A. For example, the distance between each trajectory and every other trajectory can be calculated and placed within the distance matrix. Various techniques are described herein that can be used to calculate the entries in the distance matrix.

[0046] At block 406, for each node, sort all other nodes in the order from the nearest to the
15 furthest distance to a given node. At block 408 all nodes can be assigned into one initial group, for example, group 0, and the group can be pushed into the clustering queue. At block 410 the clustering queue is checked to determine whether the clustering queue is empty. If it is, clustering is complete and process 400 proceeds to block 418. If the clustering queue is not empty, then the head group of nodes is pulled from the queue a clustering is performed
20 over the nodes within this group at block 412. At block 414, post process can be performed on the resultant groups. Groups that require further processing are pushed into the clustering queue at block 416.

[0047] Post-processing, in block 414, for example, can include three stages. First, both
25 mean and standard deviation of the trajectory lengths of the nodes (each node representing a trajectory) within the group are calculated. Only those nodes which lengths within a certain range (a preset scale times the standard variation of the length) around the mean length are kept and the others that are either too long or too short are considered as outliers and removed from this group. Second, the group is removed if its number of nodes is less than a preset threshold. Third, determine whether the group requires further clustering. If the mean
30 trajectory length is less than 2 times its length standard deviation, push it into the clustering queue at block 416; otherwise, the group is considered as a final resultant group, and sent to step 418 for cluster based analysis.

[0048] Referring to FIG. 5, process 500 for clustering nodes within a group through iterative local node grouping includes the blocks shown. Process 500, like all processes described herein, is an example only and is not limiting. Process 500 can be altered, e.g., by having blocks added, removed, rearranged, combined, and/or performed concurrently. For example, process 500 can perform the clustering shown in block 412 of FIG. 4 or block 220 of FIG. 2. In some embodiments, in-group clustering can iteratively form sub-groups of input nodes by gradually merging neighboring nodes that are not yet clustered according to a predefined merging criterion, and then pick the best sub-group as the next new group (cluster) until no further new group can be formed.

10 [0049] Each of the input nodes is treated as a seed trajectory at block 505 (three samples are given as nodes 1, 2 and t). At block 510, the seed trajectories can be centered on which local group is formed by combining the seed's nearest neighbors, for example, using process 600 shown in FIG. 6. As a result, each input node has its own local group (510-1, 510-2, 510- t). The quality of the local group can be measured by its compactness, an indicator about how close the nodes inside this group are. The smaller the average distance over all edges (e.g., over all possible pairs of nodes) within the group, the more compact the group is, and better the group's quality.

[0050] At block 515, the nodes can be separated into two types of groups: singleton groups and non-singleton groups. If a local group has two or more nodes, it is a non-singleton group, and it is added to the set of non-singleton groups at block 520; otherwise, it is a singleton group and added to the set of singleton groups at block 525. The existence of a singleton group indicates that the related seed node is far away from other nodes in a sense of direct distance. At block 530 the set of non-singleton groups are checked to determine whether any non-singleton groups exist. If so, the nodes from all existing non-singleton groups are sorted in decreasing order of compactness at block 535. This can be done using any type of sorting algorithm. And, at block 540 the nodes are analyzed one by one to determine whether they are a true new group and, if so, they are labeled as such at block 545. A group can be considered a true new group if all its nodes do not belong to any previous new group, or its nodes belonging to previous groups take over the continuous locations at the end of its node index set as determined in process 600 shown in FIG. 6.

[0051] After confirming all candidate local groups, for each of those non-singleton groups not accepted, its ungrouped nodes (the nodes not clustered into any new group) are moved

into a residual node group at block 550 and the residual node group is updated with the new residual nodes at block 555. The residual node group can include the nodes that are not assigned to any of the new groups. All nodes in the residual node group are then sent back to block 505 for THE next iteration of in-group clustering. The process continues until all local
 5 groups are singleton groups as identified in block 530, and the iterative clustering process terminates and goes further to the a post process at block 512. The final residual node group and all previously obtained new groups are the final resultant groups, which are further sent to the post process stage.

[0052] Referring to FIG. 6, process 600 for constructing a group of nodes centered at a seed
 10 node includes the blocks shown. The goal of process 600 is to keep the trajectory seed's available nearest neighbors merged into a group until the merging criterion is broken. Process 600 is an example only and is not limiting; it can be altered, e.g., by having blocks added, removed, rearranged, combined, and/or performed concurrently. Process 600 starts at block 605 and at block 610 an input node is picked as a trajectory seed. At block 615 process
 15 parameters can be initialized. For example, the following parameters can be set: G the set of nodes in the local group, n_g the number of edges (e.g., the number of pairs of nodes) in group G , s_g the sum of the distances of the edges in group G , a .
 Although these initialization values are shown as specific values, these values are used as an example only. Any value can be used for initialization. The next available nearest neighbor
 20 n of the seed can be picked at block 620. At block 625, the distance to the seed from the distance matrix can be retrieved.

[0053] If the distance is less than 2 times the average δ as checked in block 630, the four parameters are updated at block 635. Otherwise process 600 proceeds to block 645. For example, the parameters can be updated as follows: the number of edges increases by the
 25 number of nodes in G (e.g., the number of new edges that connecting existing nodes in G to the selected neighbor), and the sum of the distances of the edges, s_g , increases by the distance of these added edges. Then neighbor n is added to G and the average distance δ is also updated through a weighting function. After the parameters are updated in block 635, the remaining neighbor nodes are checked at block 640. If any neighbors remain unconsidered
 30 then the next run iteration is launched by returning to block 620. Otherwise, no further grouping is required and process 600 proceeds to block 645.

[0054] Returning to block 630, if the selected neighbor is at least 2 times of the average distance from the seed, this node is not qualified to be a member of the group centered at the seed. Then process 600 proceeds to block 645. If G has only the seed as checked in step 645, then G is a singleton group and a flag is attached to it in block 650. This flag can be used to block the seed's further grouping in later iterations. If G has two or more nodes, a local group G_i is formed in step 655 and its average over all edges in this local is calculated and saved in δ_i , serving as an indicator of the compactness of G_i .

[0055] As aforementioned, three runs of clustering process 600 can be employed to learn scene activity patterns. Runs 1 and run 2 are intended for preprocessing to remove outlier trajectories in the training data set and run 3 is the formal process for trajectory pattern discovery. Runs 1 and 2 are not required if the training data set are preprocessed with outlier removal. When runs 1 and 2 are adopted, they are implemented in the same way as the above proposed clustering process, but with minor modifications to speed up the process. For example, in run 1, the distance measure takes distance measure 1, and the weighting average is replaced by direct arithmetic average that is the average over all distances from neighbors to the seed. In run 2, the distance measure takes distance measure 2, and the weighting average is replaced by direct arithmetic average. Run 3 can takes the clustering process 600 with distance measure 3.

[0056] In run 1 clustering, the measure of Hausdorff distance measure d_{ab}^{\max} , distance 1, described above, can be adopted since this measure is prone to exhibit the differences between trajectories. For example, the value of d_{ab}^{\max} can be large even if one trajectory is part of the other in their coordinates. By using d_{ab}^{\max} trajectories in each resultant cluster are considered similar in a conservative and serious sense. That means, only truly similar trajectories can belong to a same cluster. Human operator can remove the outlier clusters through a user friendly interface. The remaining un-clustered trajectories are not removed unless they are done by human operation. The objective of run 1 clustering is to provide candidate outlier cluster to be removed by human operator while having weird trajectories automatically removed through the post-processing of each child cluster.

[0057] In run 2 clustering, the measure of distance 2 d_{ab}^{\min} , described above, is adopted, which results in clusters that are able to tolerate the difference among trajectories in a group. For example, trajectories assigned into a same cluster may still differ significantly per human

judgments. An example of this situation is that two trajectories' distance $d_{ab}^{\min} = 0$ even if one is part of the other in their observations' coordinates. The objective of run 2 clustering is to have the weird trajectories automatically removed through the post-process of each child cluster.

5 [0058] In run 3 clustering, the measure of distance 3, described, above is adopted. Due to the use of averaging operating in distance 3, this measure takes into account every distance between each observation of one trajectory to the other trajectory. As a result, it could be a true overall indication about the distance between two trajectories. It is not as sensitive as distance 1 does in run 1 clustering, nor is it as tolerant as distance 2 in run 2 clustering.

10 [0059] After clustering, scene activities in the training data set are reduced into a number of groups, each group consisting of the trajectories that are spatially close to each other and forms a specific cluster in terms of its spatial distribution in the scene, for example, a spatial pattern of scene activities. As an example, FIG. 7B shows the color-coded trajectory clusters derived from traffic training trajectory data shown in FIG. 7A. Obviously, the learnt clusters
15 correctly reveal traffic flow patterns that correspond to traffic routes on the site.

[0060] Given a learnt group G_i , the statistical information can be extracted by taking into account all its constituent trajectories over the geometrical locations which are visited. A mechanism is needed to propagate the influence of a trajectory in its surrounding areas so that its features, such as, object width, height, occurrence time, moving direction and speed, for
20 example, the group it belongs to, etc. can be conveyed into its spatial neighboring locations. To this end, an influential region for a trajectory in its surrounding areas can be defined. For example, FIG. 10 presents a trajectory with 4 observations (4 objects denoted by solid squares) at locations A, B, C and D. Its influential region is the inside area bounded by the enclosed dotted line which is centered at the path A->B->C->D of the trajectory, and the
25 boundary is away from the closest location of the path a distance that is a preset proportion (for example, in FIG. 10 it is 0.5) of an interpolated width at the closest location.

[0061] To calculate the interpolated width at location P in FIG. 10, first find the base P' of the perpendicular dropped from P to path segment AB; then estimate the object's width at P' using a linear interpolation between the two object widths respectively at A and B. Similarly,
30 an estimate of the height, and time occurrence, etc. can also be made. And, the direction and speed from A to B for an object at location P' can also be used. Further, any feature estimated for P' are conveyed to P as long as this trajectory is concerned, which will be taken

into consideration in the calculation of statistical features of the affiliated group. Locations outside the influential region are unaffected by this trajectory.

[0062] With the concept of influential region, group based features can be thus calculated. Define (x, y) the horizontal and vertical coordinates of a location in the scene, dir moving direction with discrete values from 0 to 8 representing respectively the direction: unknown (a special direction, e.g., keeping stationary, which is none of the following 8 deterministic directions), right move, forward-right move, forward move, forward-left move, left move, back-left move, back move, and back-right move. The following statistical features are defined:

10 [0063] $avg_width_i(x, y)$: group G_i 's average object width at location (x, y) , which is defined as the average of all estimated widths at location (x, y) overall all constituent trajectories of this group.

[0064] $std_width_i(x, y)$: group G_i 's standard derivation of object weights at location (x, y) , which is defined as the standard derivation of all estimated widths at location (x, y) overall all constituent trajectories of this group.

[0065] $avg_height_i(x, y)$: group G_i 's average object height of object height at location (x, y) , computed in a similar manner as $avg_width_i(x, y)$.

[0066] $std_height_i(x, y)$: group G_i 's standard derivation of object heights at location (x, y) , computed in a similar manner as $std_width_i(x, y)$.

20 [0067] $avg_speed_i(dir, x, y)$: group G_i 's average speed in direction dir at location (x, y) , computed in a similar manner as $avg_width_i(x, y)$.

[0068] $std_speed_i(dir, x, y)$: group G_i 's standard derivation of speed in direction dir at location (x, y) , computed in a similar manner as $std_width_i(x, y)$.

[0069] $prob_dir_i(dir, x, y)$: group G_i 's probability of having moving direction dir at location (x, y) . For each location, a histogram of 9 bins with each bin corresponding to one of the 9 discrete directions defined above can be set such that it keeps the counts of the moving direction of influential trajectories in group G_i that has this direction, and then the histogram is normalized to make its sum to one.

[0070] $prob_i(x, y)$: cluster probability of G_i at location (x, y) . This probability is 0 if location (x, y) is not within any of the influential region of G_i 's constituent trajectories.

Otherwise, for each of the resultant groups find its trajectories which influential regions cover location (x, y) , and then compute the probability of the group by accumulating that contributed by those influential trajectories through a triangle kernel function (with the highest value 1 on the trajectory and zero on influential boundaries, decreasing with distance to the trajectory), finally normalize the probability of the influential groups such that their sum is one. This way, $prob_i(x, y)$ denotes the likelihood of location (x, y) belonging to G_i . $prob_i(x, y)$ ranges from 0 to 1. It has a value of one when (x, y) is only in the influential regions of G_i 's trajectories. A representation of cluster map of scene activities, e.g., FIG. 7C representing the cluster map related to FIG. 7B, can be obtained, if a distinction between groups with a different non-zero label value and assign the label value of the group with the maximum cluster probability for each location in the scene while 0 is assigned to locations that are not in any influential regions of groups.

[0071] $prob_hourly_i(h, x, y)$: group G_i 's occurrence probability at location (x, y) over daily 24 hours. For each location, a histogram of 24 bins with each bin corresponding to an hour period can be set. For example, the first bin keeps the record about how many trajectories in group G_i impact the location (x, y) from 12:00 PM to 1:00 AM in the training data set. Here, impact means location (x, y) is within the influential region of the trajectory under consideration. The histogram is normalized to make its sum to one over the 24 bins, and thus the value of a bin representing the occurrence probability in the corresponding period of hour.

[0072] Semantic features can be also derived from a cluster of trajectories if these trajectories have one coherent moving direction within the influential region of the cluster, and the these feature may include an entry zone which is the starting part of the cluster's influential region, an exit zone which is the ending part of the cluster's influence region, a representative trajectory which is defined as the one among the cluster's constituent trajectories which has the minimum average distance to any of the others in terms of distance measure 3. FIG. 7D plots an example of an entry zone by a black rectangle and an exit zone by a green rectangle for a cluster. Further analysis can be conducted on each representative trajectory to find its pivotal points. A pivotal point is a location on the trajectory where there is a large direction change. Also, with clusters' representatives in the scene, their intersection points can be obtained. Consequently, a representative trajectory can be simplified and thus modeled as a sequence of pivotal points and intersection points along its moving direction. FIG. 7E plots representative trajectories for all resulted clusters in FIG. 7B, each having

pivotal and intersection points indicated by small rectangles. A color-coded trajectory in FIG. 7E is the representative of a cluster coded by the same color in FIG. 7B.

[0073] With the above statistical features, a new trajectory appearing in the scene can be classified into a cluster (a normal scene activity) or not belonging to any cluster (an abnormal scene activity) from a viewpoint of the training dataset. For a trajectory T, a similarity score is calculated about to what degree it belongs to each of the learnt clusters by taking into consideration the statistical features, and then the maximum score is adopted as its best score. If this best score is less than a preset threshold, the trajectory is considered not belonging to any learnt cluster. Otherwise, it is a normal activity and it belongs to the cluster that has the largest score.

[0074] A similarity score is calculated by a weighted sum of the individual scores resulted from the trajectory's primitives, such as object width, object height, moving speed, moving direction, spatial location, occurrence time over all locations on the trajectory against the learnt clusters' statistics:

$$\begin{aligned}
 15 \quad score_i &= w_1 \times score_width_i \\
 &+ w_2 \times score_height_i \\
 &+ w_3 \times score_speed_i \\
 &+ w_4 \times score_dir_i \\
 &+ w_5 \times score_prob_i \\
 20 \quad &+ w_6 \times score_prob_hourly_i
 \end{aligned}$$

where w_i is the weight of a feature, and they control the impact of the related feature in the final score. Single-feature based scores are computed as follows:

$$\begin{aligned}
 score_width_i &= \frac{1}{\|T\|} \sum_{(x,y) \in T} e^{-\frac{(width(x,y) - avg_width_i(x,y))^2}{(2 \times std_width_i(x,y))^2}} \\
 score_height_i &= \frac{1}{\|T\|} \sum_{(x,y) \in T} e^{-\frac{(height(x,y) - avg_height_i(x,y))^2}{(2 \times std_height_i(x,y))^2}} \\
 25 \quad score_speed_i &= \frac{1}{\|T\|} \sum_{(x,y) \in T} e^{-\frac{(speed(x,y) - avg_speed_i(x,y))^2}{(2 \times std_speed_i(x,y))^2}}
 \end{aligned}$$

$$score_dir_i = \frac{1}{\|T\|} \sum_{(x,y) \in T} prob_dir_i(dir(T,x,y),x,y)$$

$$score_prob_i = \frac{1}{\|T\|} \sum_{(x,y) \in T} prob_i(x,y)$$

$$score_hourly_i = \frac{1}{\|T\|} \sum_{(x,y) \in T} prob_hourly_i(h(T,x,y),x,y)$$

[0075] [0076] In the above, a similarity is obtained for each location (x,y) on trajectory T and then are summed and averaged by $\|T\|$. $\|T\|$ denotes the cardinality of T , as is the number of locations of T involved in the summation calculation. For features such as object width, object height, and moving speed, a Gaussian function is used to calculate the similarity to group G_i at a location (x,y) on T . The similarity of direction at (x,y) is G_i 's direction probability for the matched direction $dir(T,x,y)$. The similarity of occurrence time at (x,y) is G_i 's occurrence probability at T 's occurring hour $h(T,x,y)$ at location (x,y) .

[0077] By purposely adjusting the values of weights, different results can be achieved. For example, if w_4 is set to one and the others are 0, an object moving in a wrong direction even within an influential region of a cluster will be detected as abnormal activity. On the other hand, if w_5 is set to one and the others are 0, an object moving in a wrong direction within an influential region of a cluster will be considered as normal activity. Therefore, options can be left to human operators for them to detect abnormal activities of interest.

[0078] An example of normal scene activity and abnormal activity is presented in FIG. 7F, where the pedestrian crossing the road is detected as abnormal activity (represented in red color) while the car is classified as a normal activity (its trajectory is in green color).

[0079] If a new trajectory is classified into a cluster, it can be further annotated by using the semantic features of the belonged cluster, to generate additional information about the trajectory's status, e.g., time instants when it enters the cluster, passes pivotal points and crossing points, and leaves the cluster. Accordingly, its relative moving directions can be generated, such as turn left, turn right, etc. Moreover, the annotated trajectories can be stored in much efficient manner than saving the all original (normal) trajectories and reduce storage space.

[0080] For activity summarization, a dataset of trajectories are assumed available. When the proposed method is applied to areal-time application, the training data set can be collected during a certain period of time (e.g., 1 day, a couple of days, 1 week, a couple of weeks, or months) to get enough trajectories. Once the initial training data is obtained, the above method can be used to learn the clusters of scene activities, and extract statistical features and semantic features. These features can be used for real-time analysis of new object trajectories. Another online learning scheme is required to update existing clusters and their derived features so that the scene activity analysis system can keep reflecting the nature of normal scene activities. This can be achieved by three extra processes: replace the oldest constituent trajectory of the belonged cluster of a new normal trajectory which is controlled by a replacement probability depending on the new trajectory's primitives such as occurring time, spatial location, etc; remove an obsolete cluster if it has not been updated for a preset time (i.e., no new trajectory is classified as this cluster for a preset time); create new clusters if abnormal trajectories occur frequently and constantly over a preset time period, then apply the above clustering process to the abnormal trajectories that occurred in the past time of preset period and form new clusters if possible. Every time a cluster is updated, an old cluster is removed, or a new cluster is created, related features are update correspondingly, and the future scene analysis is based on the updated features consequently.

[0081] Referring to FIG. 8, process 800 for analyzing trajectories and alerting a user in the event an abnormal trajectory is identified includes the blocks shown. Process 800 is an example only and is not limiting; it can be altered, e.g., by having blocks added, removed, rearranged, combined, and/or performed concurrently. Process 800 begins at block 805. At block 810, process 800 video data about a scene of interest is obtained. In some embodiments, the video data can be obtained from a database that contains the video data. In some embodiments, the video can be obtained directly from a video camera or video acquisition system. Moreover the video data can be obtained in real time as the video data is acquired. Video data can also include metadata. The metadata can include data about objects viewed within a video scene and/or events that occur within the video scene.

[0082] At block 815 trajectories can be identified. In some embodiments, trajectories can be identified by searching the metadata. In other embodiments, trajectories can be found by searching the video data for objects that move through the scene over time. Various techniques can be used for identifying trajectories. At block 820 trajectories can be clustered according to their relative distance from each other. Various techniques can be used for

clustering. And many such techniques are described herein, for example, clustering based on similarities between statistical features between trajectories and/or clustering between similarities between trajectory positions. From the clustering, the trajectories can be identified as either normal or abnormal at block 825. Similarly, any number of techniques
5 can be used to identify trajectories as normal or abnormal as described herein. An abnormal trajectory is a trajectory that is unassociated with a group of trajectories or a cluster of trajectories.

[0083] If a trajectory is identified as normal, at block 830, then process 800 proceeds to block 835 where semantic data is extracted from the trajectory or video data (including the
10 metadata). At block 840 normal trajectories can then be annotated with the semantic data. Process 800 can then end at block 845. If, however, a trajectory is identified as an abnormal trajectory at block 830, then a user can be alerted at block 850. Process 800 ends at block 845. A user can be alerted in a number of ways. For example, a signal can be sent to a user interface or an alarm can be sounded. The video data that includes the abnormal trajectory
15 can be flagged or labeled as having an abnormal trajectory.

[0084] Referring to FIG. 9, computer system 900 includes a processor 905, memory 910, user interface 920, and video capture or input system 915 (herein referred to as video system 915). Processor 905 is a programmable device, e.g., a central processing unit (CPU), such as those made by Intel® Corporation or AMD®, a microcontroller, an application specific
20 integrated circuit (ASIC), a field-programmable gate array (FPGA), etc. Processor 905 processes information received from video system 915 and performs functions associated with the computer system 900 such as, for example, guidance, navigation and control functions. Memory 910 includes random access memory (RAM), read-only memory (ROM), and/or a hard drive. Memory 910 stores a non-transitory computer program product comprising
25 processor-readable, processor-executable software code containing instructions that are configured to, when executed, cause the processor 905 to perform various functions or processes described herein (e.g., any of process 100, 200, 400, 500, 600, and/or 800). Alternatively, the software may not be directly executable by processor 905 but configured to cause processor 905, e.g., when the instructions are compiled and executed, to perform any of
30 the functions described. User interface 920 can include a display and input devices such as a mouse and a keyboard. Moreover, user interface can be used by a user to enter various parameters (e.g., the parameters discussed in relation to block 615 and 635 shown in FIG. 6) and/or data input from user 230 shown in FIG. 2.

- [0085] Other examples of configuration (including implementations) are within the scope and spirit of the disclosure and appended claims. For example, due to the nature of software, functions described above can be implemented using software executed by a processor, hardware, firmware, hardwiring, or combinations of any of these. Features implementing functions may also be physically located at various positions, including being distributed such that portions of functions are implemented at different physical locations. Also, as used herein, including in the claims, “or” as used in a list of items prefaced by “at least one of” indicates a disjunctive list such that, for example, a list of “at least one of A, B, or C” means A or B or C or AB or AC or BC or ABC (i.e., A and B and C).
- 5
- 10 [0086] As used herein, including in the claims, “or” as used in a list of items prefaced by “at least one of” indicates a disjunctive list such that, for example, a list of “at least one of A, B, or C” means A or B or C or AB or AC or BC or ABC (i.e., A and B and C). A wireless communication network does not have all communications transmitted wirelessly, but is configured to have at least some communications transmitted wirelessly.
- 15 [0087] Further, more than one invention may be disclosed.

WHAT IS CLAIMED IS:

- 1 1. A method for providing trajectory information about a video scene, the
2 method comprising:
3 obtaining video scene metadata that includes information regarding trajectories
4 for a plurality of objects moving through the video scene;
5 clustering each of the plurality of trajectories into trajectory groups according to
6 their relative distance from each other;
7 extracting statistical features about each trajectory group;
8 classifying each trajectory in the plurality of trajectories as a normal trajectory or
9 an abnormal trajectory based at least in part on the clustering;
10 extracting semantic data about each trajectory group or each normal trajectory;
11 and
12 annotating each trajectory with the semantic data.
- 1 2. The method according to claim 1, wherein the clustering comprises a
2 plurality of clustering iterations using a plurality of different distance measures.
- 1 3. The method according to claim 1, wherein the distance measure comprises
2 a distance measure selected from the group consisting of a minimum distance between
3 trajectories, a maximum distance between trajectories, and an average distance between
4 trajectories.
- 1 4. The method according to claim 1, wherein the statistical features include
2 features selected from the listing consisting of: average and standard deviation of object height,
3 object width, object size, object speed, object appearance color, object shape, trajectory length,
4 trajectory duration, as well as moving direction probability, spatial occurrence probably,
5 temporal occurrence probably.
- 1 5. The method according to claim 1, wherein the semantic data includes data
2 selected from the group consisting of entry zones, exit zones, representative trajectories, pivotal
3 points and directions of trajectory patterns, and crossing zones between different trajectory
4 patterns.

1 6. The method according to claim 1, in the event a trajectory is classified as a
2 normal trajectory further comprising annotating a normal trajectory based on the trajectories
3 association with a classified group of trajectories.

1 7. The method according to claim 1, wherein a normal trajectory is a
2 trajectory with statistical features similar to other trajectories within a group.

1 8. The method according to claim 1, wherein an abnormal trajectory is a
2 trajectory that is unassociated with a group of trajectories.

1 9. A computer program product residing on a non-transitory processor-
2 readable medium and comprising instructions configured to cause a processor to:
3 cluster each of a plurality of trajectories into trajectory groups according to their
4 relative distance from each other;
5 extract statistical features about each trajectory group;
6 classify each trajectory in the plurality of trajectories as a normal trajectory or an
7 abnormal trajectory based at least in part on the clustering;
8 extract semantic data from each trajectory group or each normal trajectory; and
9 annotate each normal trajectory with the semantic data.

1 10. The computer program product of claim 9, wherein the instructions to
2 cause the processor to cluster each of plurality of trajectories into trajectory groups comprise
3 instructions configured to cause the processor to iteratively cluster the plurality of trajectories
4 using different distance measures.

1 11. The computer program product of claim 9, wherein in the event a
2 trajectory is classified as a normal trajectory further comprising annotating a normal trajectory
3 based on the trajectories association with a classified group of trajectories.

1 12. A trajectory analysis system comprising:
2 an input configured to receive video scene metadata that includes information
3 regarding the trajectories of objects as the objects move within the video scene:
4 a memory; and

5 a processing unit communicatively coupled to the input and the memory and
6 configured to:

7 cluster each trajectory into a trajectory group according to the trajectory's
8 relative distance from previously analyzed trajectories;

9 identify each trajectory in the plurality of trajectories as a normal
10 trajectory or an abnormal trajectory based at least in part on the clustering; and

11 annotate each normal trajectory as a normal trajectory or an abnormal
12 trajectory.

1 13. The trajectory analysis system according to claim 12 wherein the
2 processing unit is configured to extract statistical features for each trajectory group, extract
3 semantic data from each trajectory group or each normal trajectory and annotate the normal
4 trajectory with the semantic data.

1 14. The trajectory analysis system according to claim 12 further comprises a
2 user interface wherein the processing unit is configured to notify the user through the user
3 interface in the event a trajectory is an abnormal trajectory.

1 15. The trajectory analysis system according to claim 12, wherein the
2 trajectory analysis system comprises a camera.

3 16. A method for determining abnormal behavior in a video scene, the method
4 comprising:

5 creating a database of normal trajectories from video data of a scene that includes
6 a plurality of objects moving through the scene along a trajectory, wherein a normal trajectory
7 comprises a trajectory that is clustered with a plurality of previous trajectories within the video
8 scene;

9 identifying a new trajectory within the video scene;

10 determining whether the new trajectory is a normal trajectory; and

11 in the event the new trajectory is not a normal trajectory, notifying a user.

1 17. The method according to claim 16, wherein a normal trajectory comprises
2 a trajectory whose distance is near a plurality of previous trajectories within a group in terms of
3 statistical feature similarities.

1 18. The method according to claim 16, wherein the creating a database of
2 normal trajectories comprises:

3 clustering each of the plurality of trajectories into trajectory groups according to
4 their relative distance from each other;

5 classifying each trajectory in the plurality of trajectories as a normal trajectory or
6 an abnormal trajectory based at least in part on the clustering; and

7 saving the results of the classification in a database.

1 19. The method according to claim 16, wherein the determining whether the
2 new trajectory is a normal trajectory comprises determining the relative distance in terms of
3 statistical feature similarities between the new trajectory and one or more of the normal
4 trajectories stored within the database.

1 20. A trajectory analysis system comprising:

2 an input configured to receive video scene metadata that includes information
3 regarding the trajectories of objects as the objects move within the video scene;

4 a user interface;

5 a memory configured to store normal trajectories from video data of a scene that
6 includes a plurality of objects moving through the scene along a trajectory, wherein a normal
7 trajectory comprises a trajectory that is clustered with a plurality of previous trajectories within
8 the video scene; and

9 a processing unit communicatively coupled to the input and the memory and
10 configured to:

11 identify a new trajectory within the video scene;

12 determine whether the new trajectory is a normal trajectory; and

13 in the event the new trajectory is not a normal trajectory, notify a user

14 through the user interface.

1 21. The trajectory analysis system according to claim 20, wherein a new
2 trajectory is identified as a normal trajectory when the new trajectory is near a plurality of
3 previous trajectories.

1 22. The trajectory analysis system according to claim 21, wherein the new
2 trajectory is identified as being near one of a plurality of trajectories based on the relative
3 distance from the new trajectory and the plurality of trajectories.

1 23. The trajectory analysis system according to claim 20, wherein a new
2 trajectory is identified as a normal trajectory when the new trajectory is similar to trajectories in
3 a cluster of trajectories based on similarities between any of the direction, speed, or appearing
4 time of the new trajectory and any trajectory in the cluster of trajectories.

1 24. The trajectory analysis system according to claim 21, wherein the relative
2 distance comprises a distance measure selected from the group consisting of a minimum distance
3 between trajectories, a maximum distance between trajectories, and an average distance between
4 trajectories.

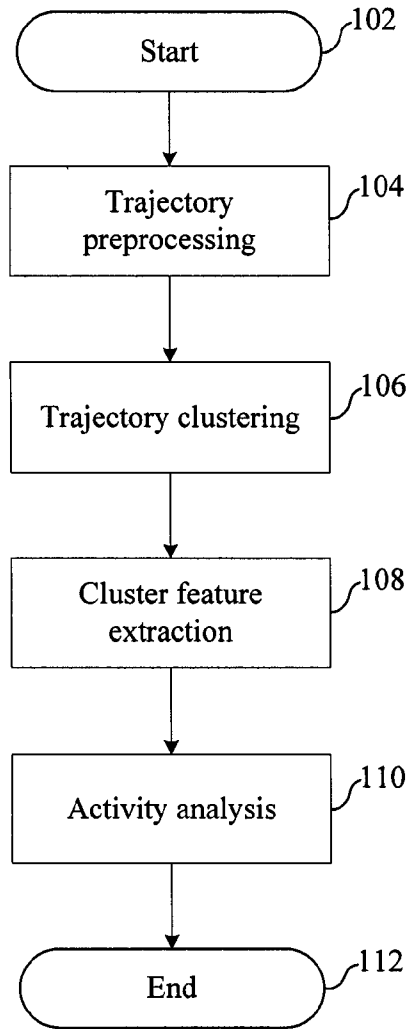


FIG. 1

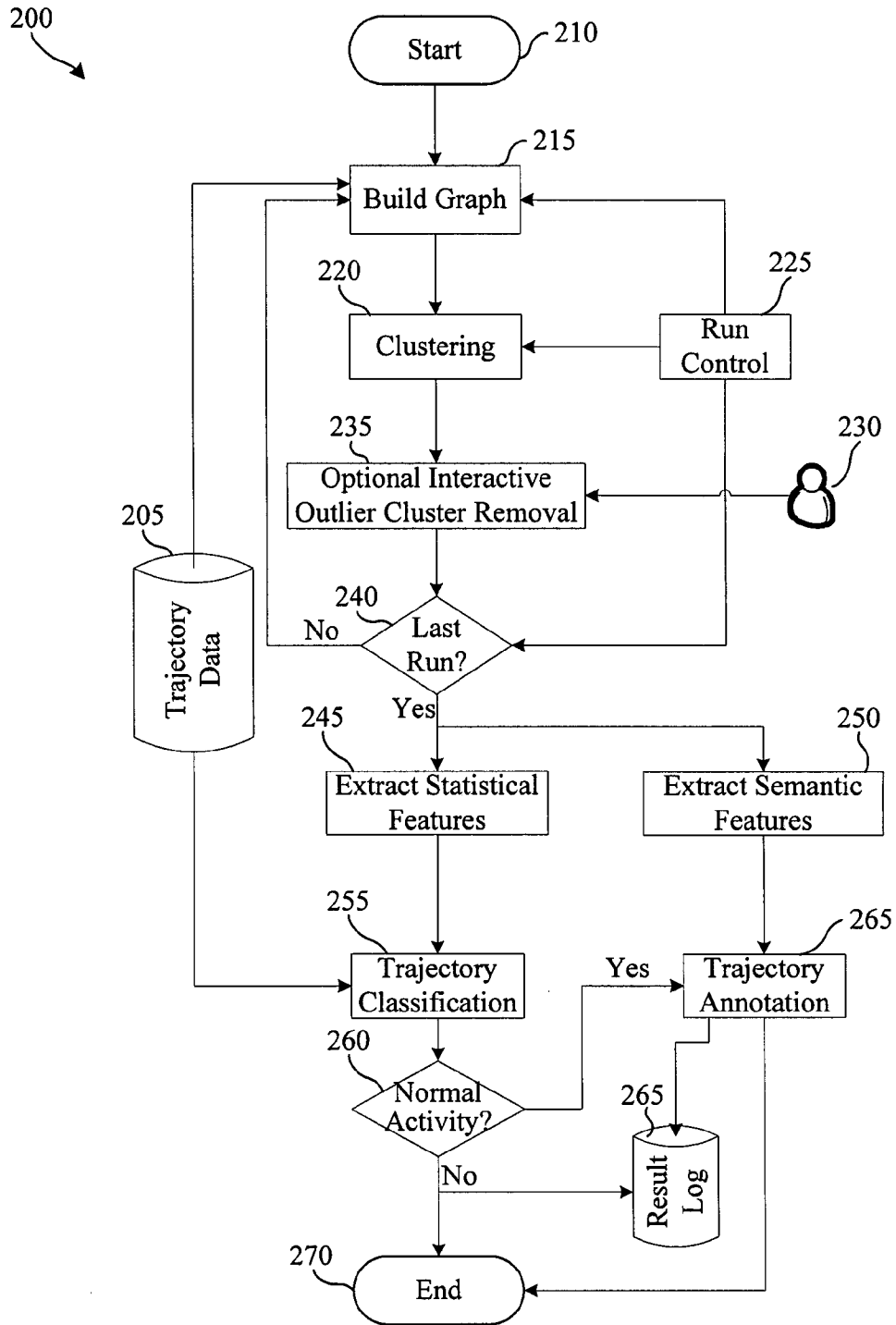


FIG. 2

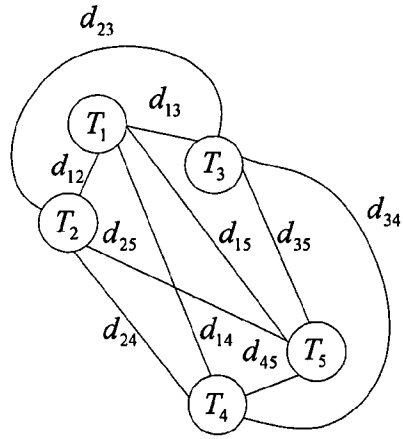


FIG. 3A

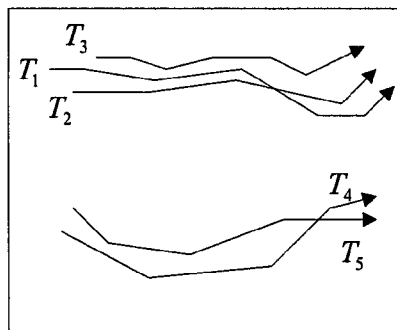


FIG. 3B

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400

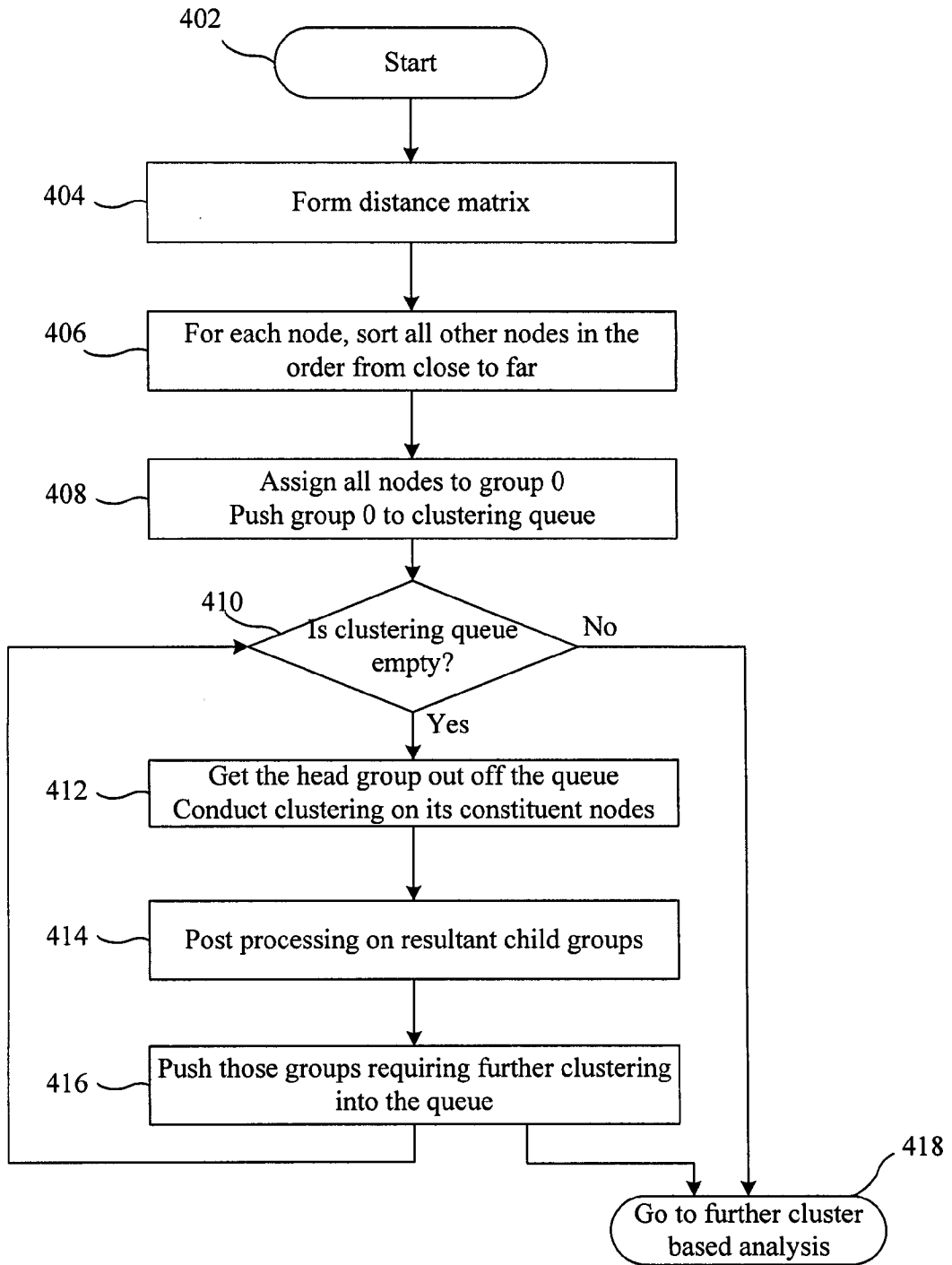


FIG. 4

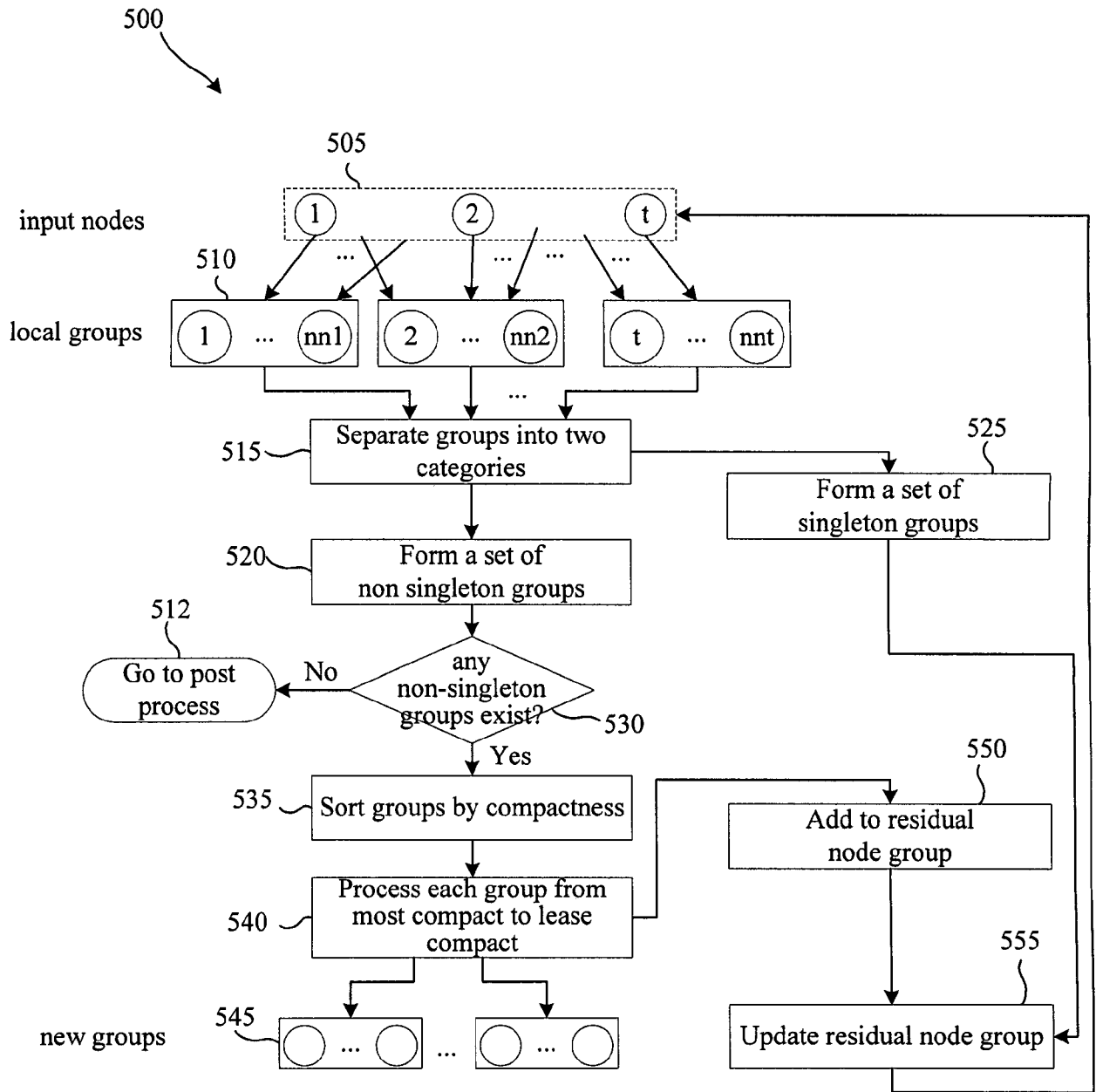


FIG. 5

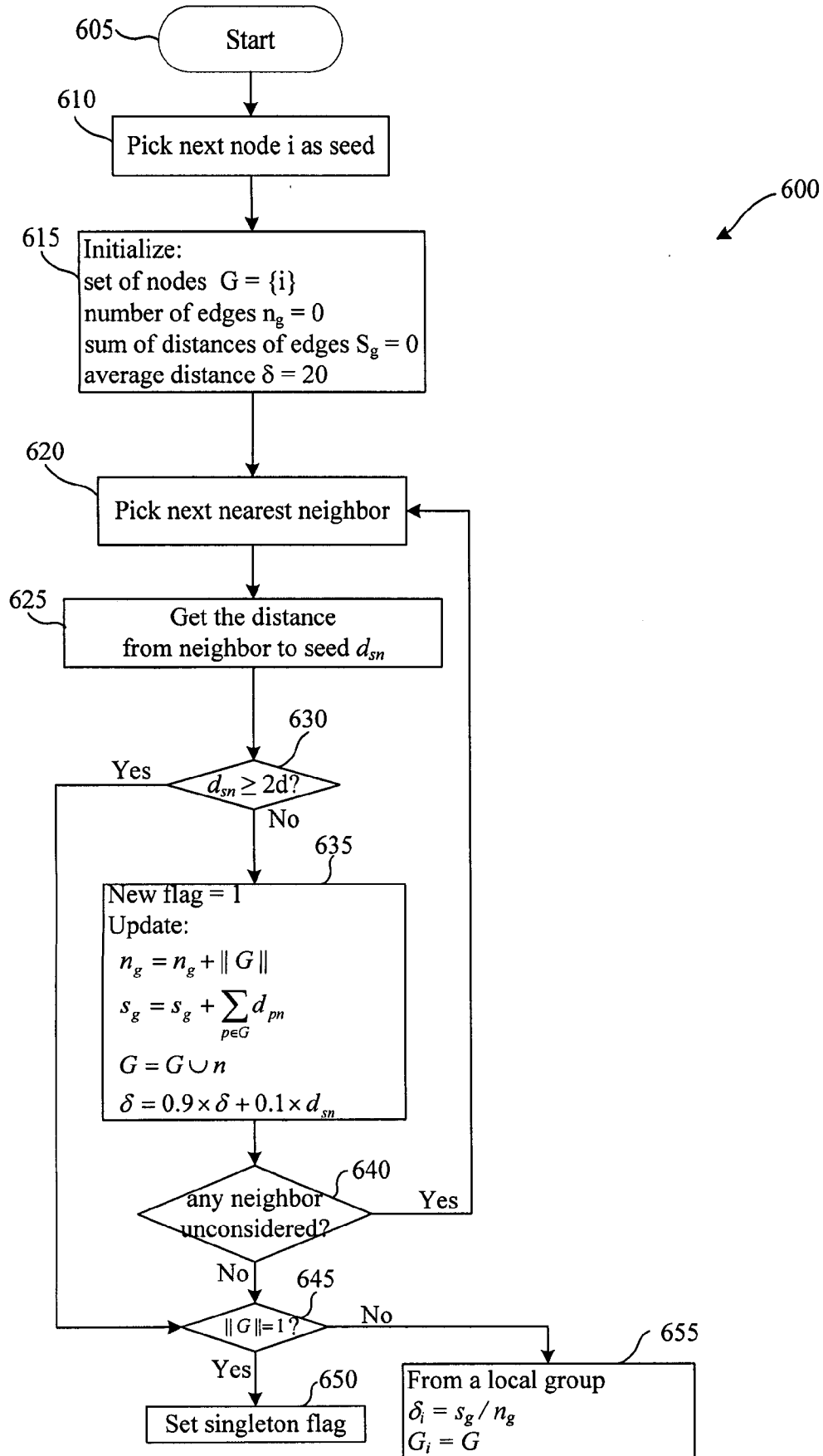


FIG. 6

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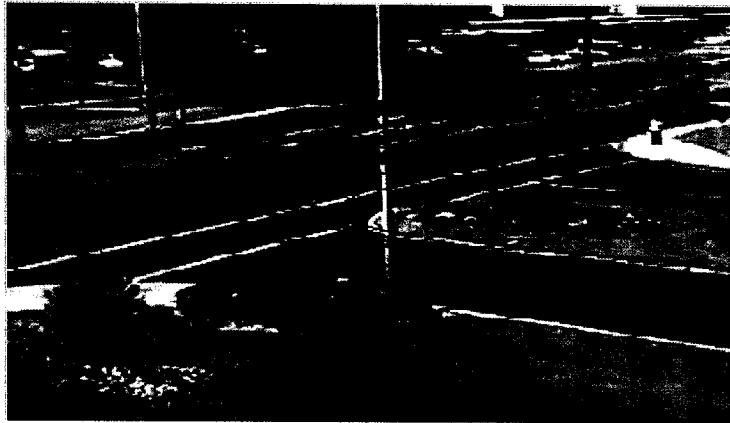


FIG. 7A

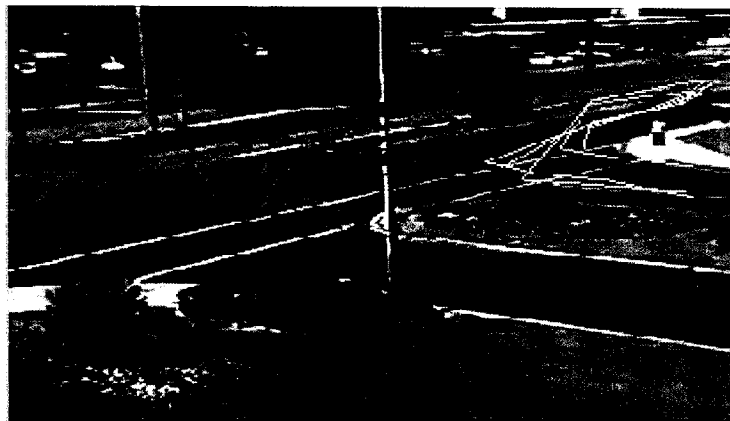


FIG. 7B

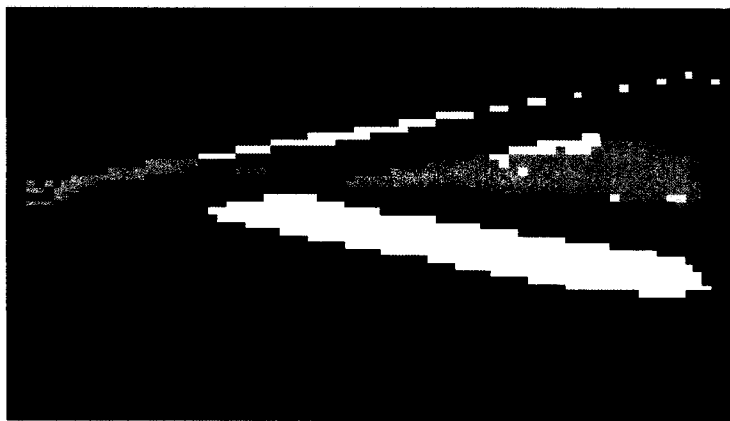


FIG. 7C

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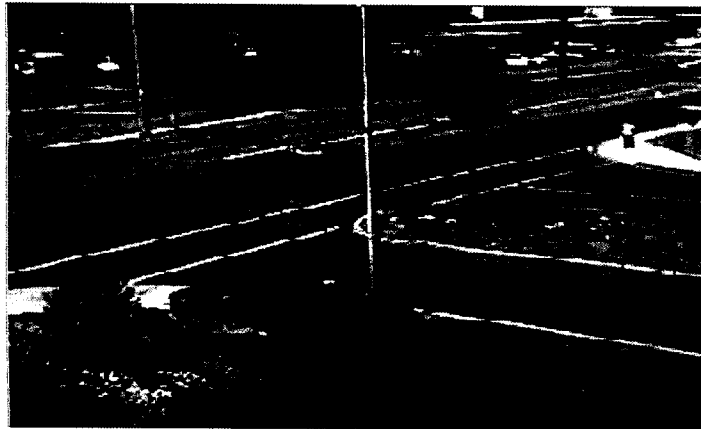


FIG. 7D

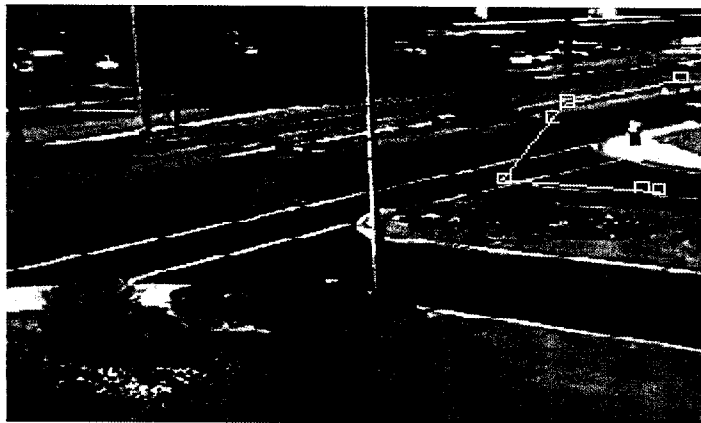


FIG. 7E

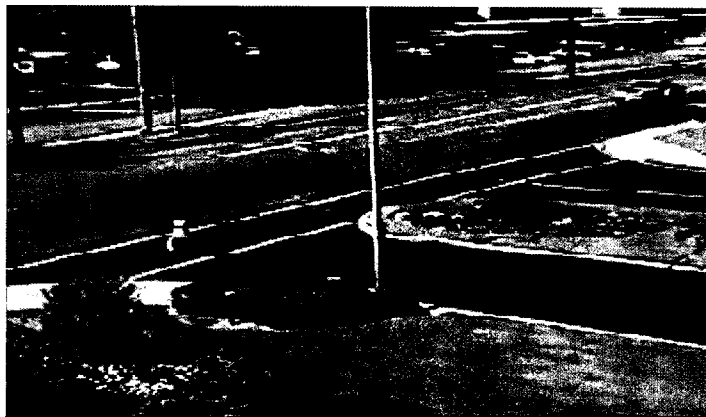


FIG. 7F

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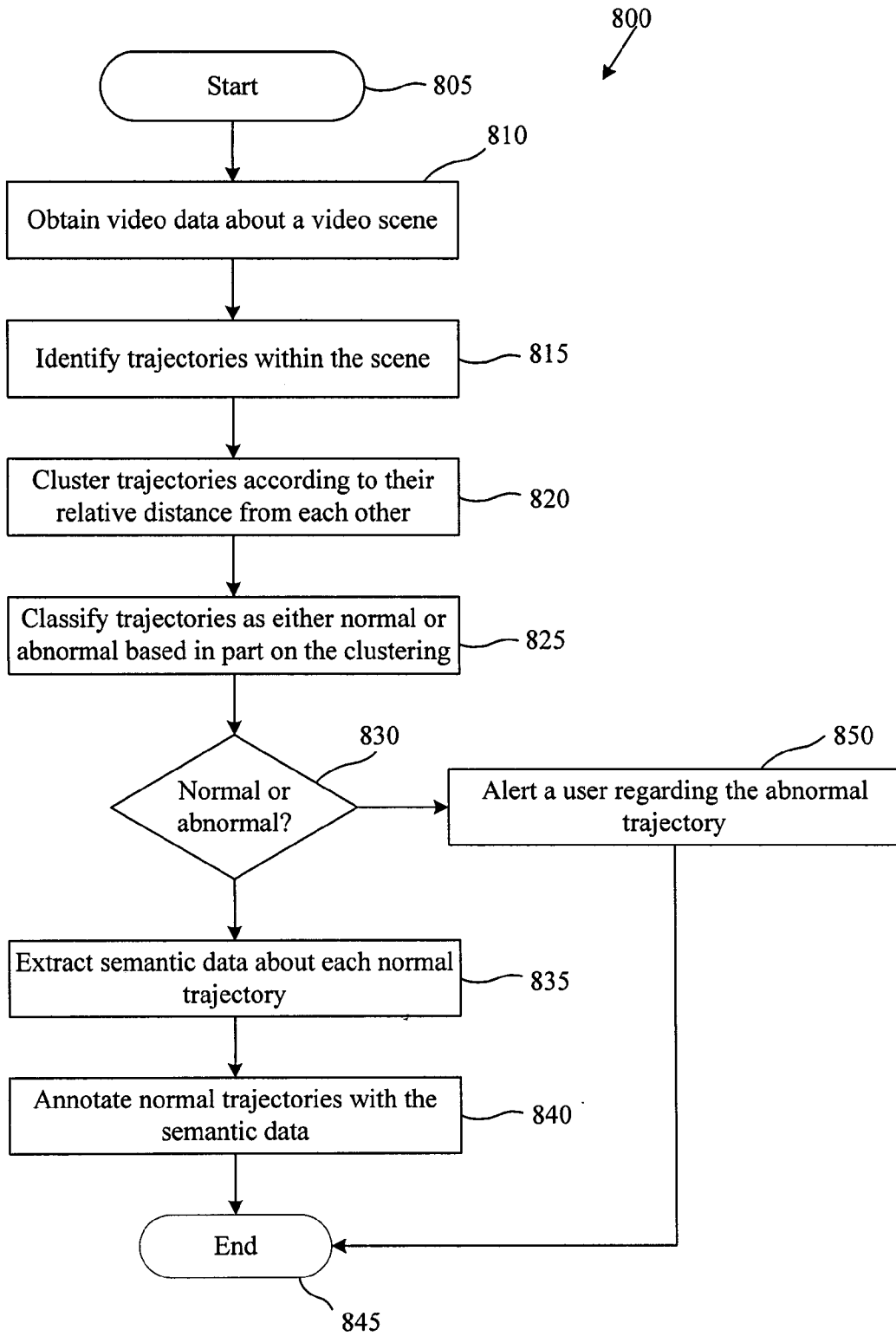


FIG. 8

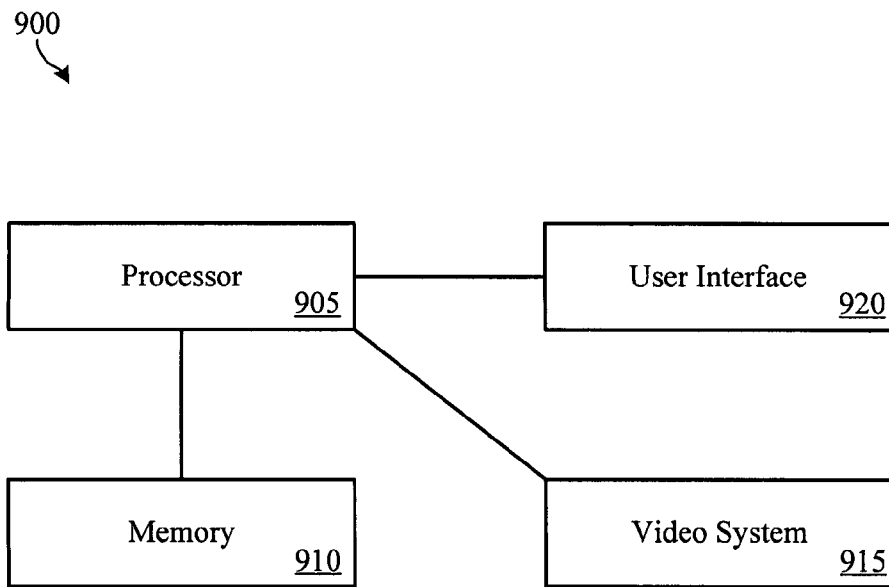


FIG. 9

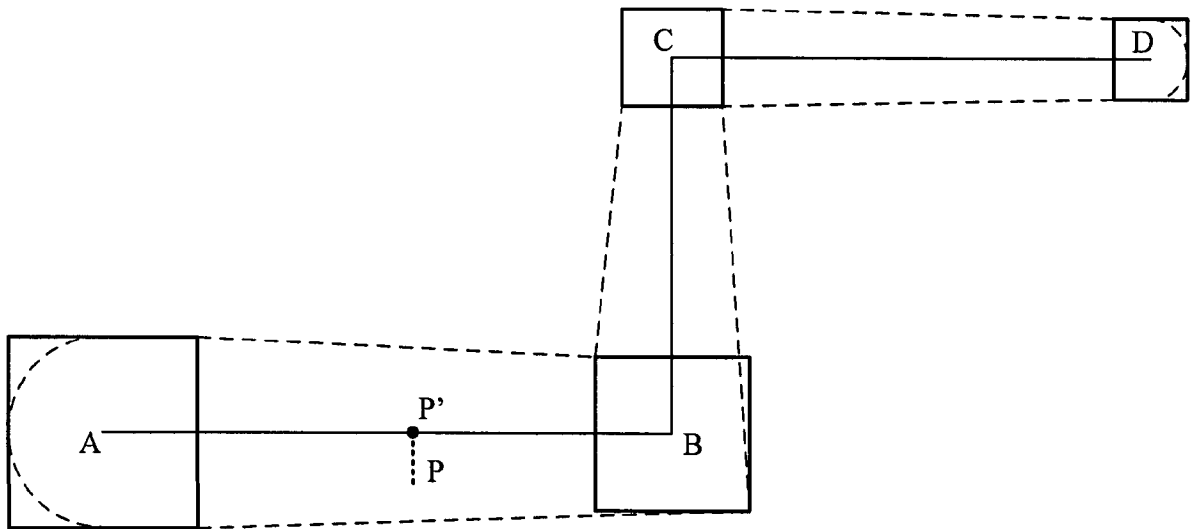


FIG. 10