US010043103B2

(12) **United States Patent**
Dodballapur et al.

(10) **Patent No.: US 10,043,103 B2**
(45) **Date of Patent: Aug. 7, 2018**

(54) **SYSTEM AND METHOD FOR OBJECT MATCHING**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/189,795**

(22) Filed: **Jun. 22, 2016**

(65) **Prior Publication Data**

US 2016/0379085 A1 Dec. 29, 2016

(30) **Foreign Application Priority Data**

Jun. 26, 2015 (AU) 2015203591

(51) **Int. Cl.**
G06K 9/62 (2006.01)
G06K 9/00 (2006.01)

(52) **U.S. Cl.**
CPC ***G06K 9/6202*** (2013.01); ***G06K 9/00778*** (2013.01); ***G06K 9/6215*** (2013.01)

(58) **Field of Classification Search**
CPC . G06K 9/6202; G06K 9/00778; G06K 9/6215
USPC 382/218, 219, 220, 181, 209; 1/1; 370/241, 259; 435/6.11, 283.1; 534/657, 534/732; 536/23.1; 707/749; 711/125, 711/135; 712/235; 714/124, E11.207; 715/229, 234, 239; 455/41.1, 73
See application file for complete search history.

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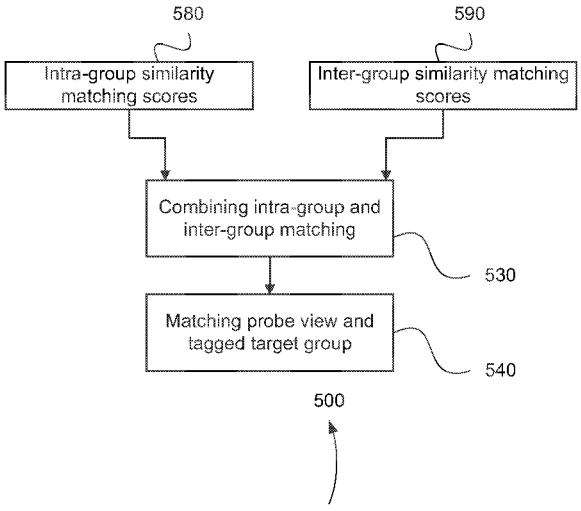
(57) **ABSTRACT**

A computer implemented method of matching a tagged target group, selected from a plurality of gallery groups in a first camera field of view, with probe groups in a second camera field of view, by determining a group context for the tagged target group, determining, in the second camera field of view, probe contexts for the respective local probe groups in the second camera field of view; matching the group context against the probe contexts to produce respective similarity scores; and identifying based upon the similarity scores, the probe group that matches the tagged target group.

11 Claims, 11 Drawing Sheets



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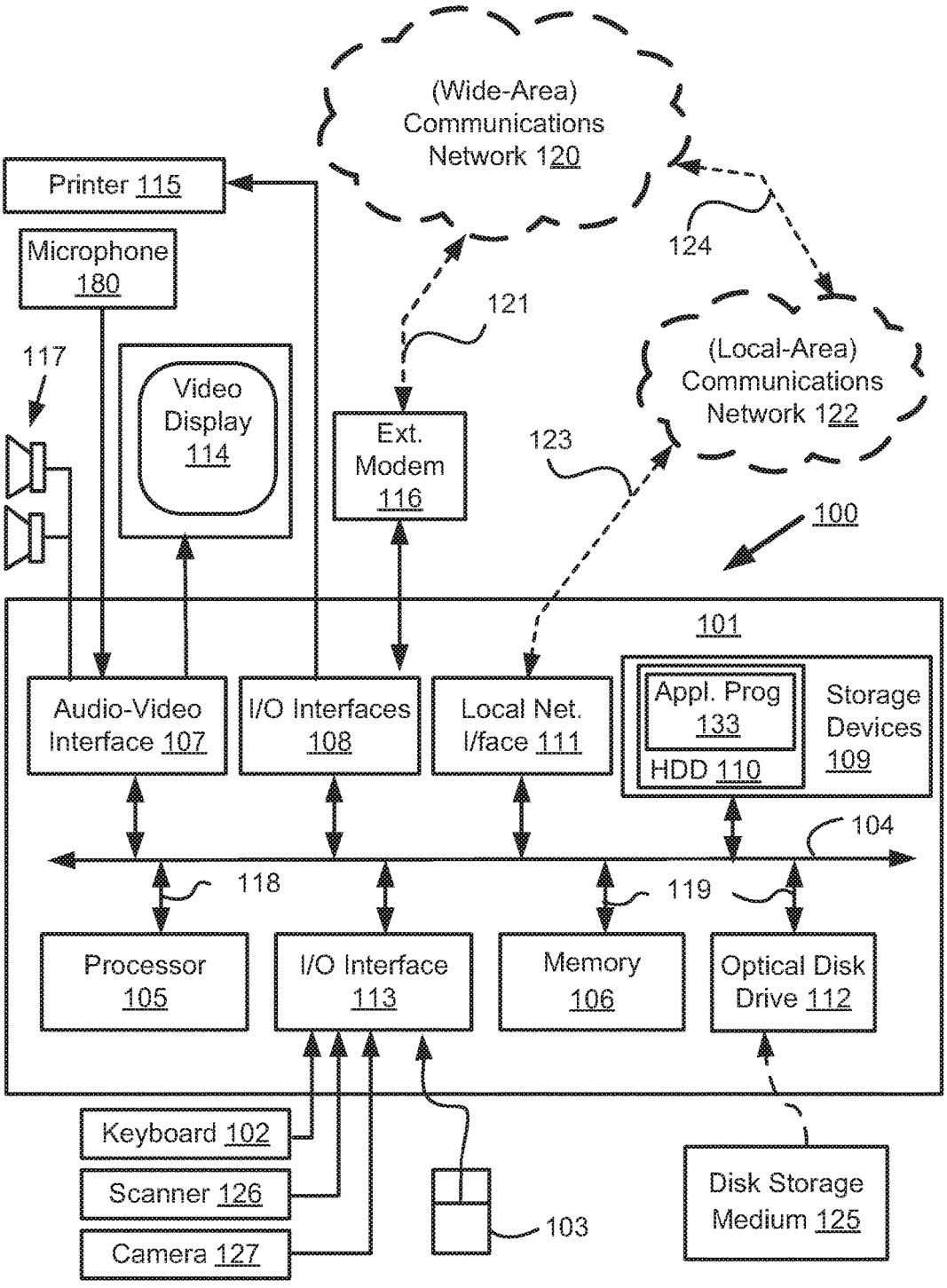
(Wide-Area) Communications Network 120
Printer 115
Microphone 180
124
121
117
Video Display 114
Ext. Modem 116
(Local-Area) Communications Network 122
123
100
101
Audio-Video Interface 107
I/O Interfaces 108
Local Net. I/face 111
Appl. Prog 133
HDD 110
Storage Devices 109
104
118
119
Processor 105
I/O Interface 113
Memory 106
Optical Disk Drive 112
Keyboard 102
Scanner 126
Camera 127
103
Disk Storage Medium 125

Fig. 1

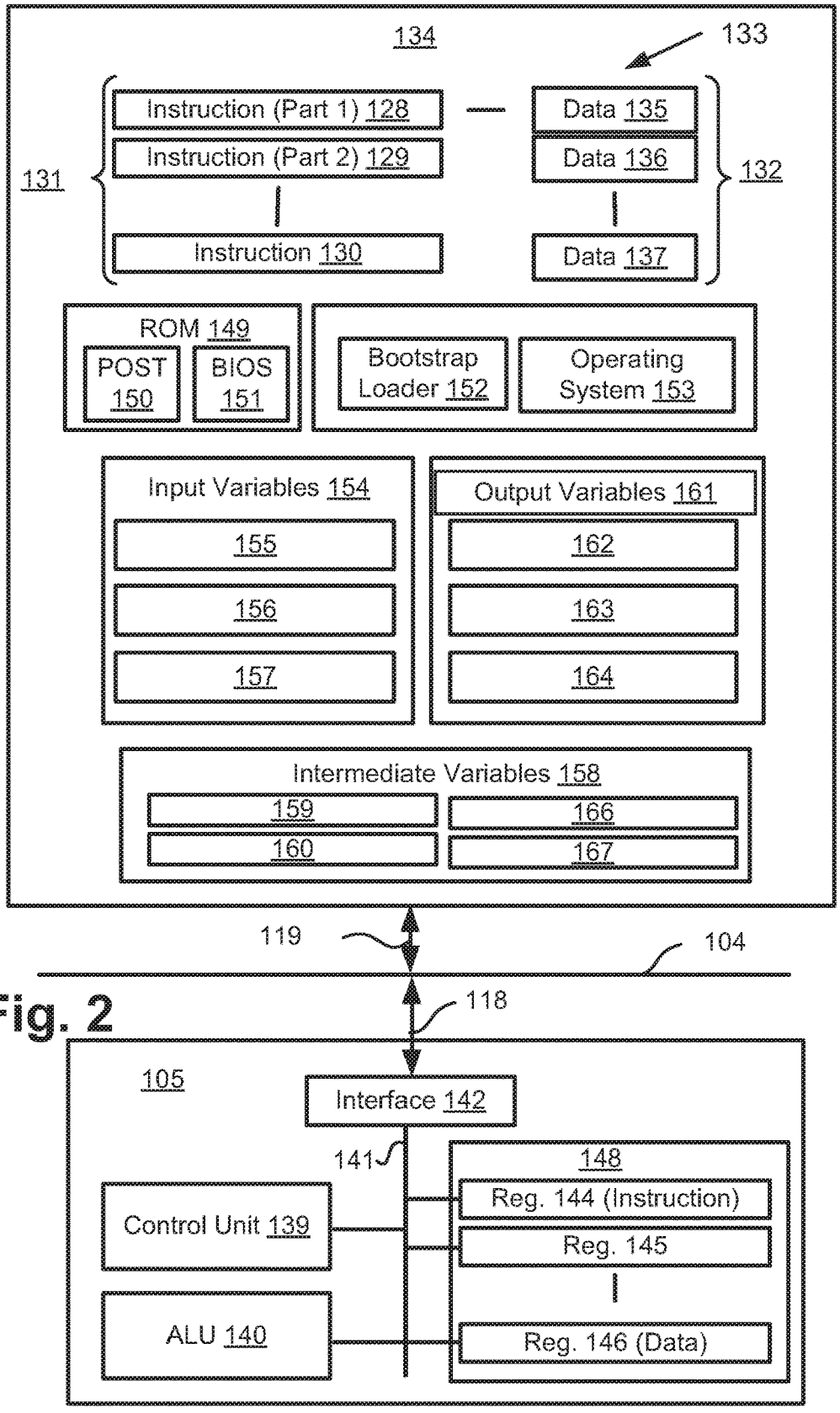
134
133
Instruction (Part 1) 128
Instruction (Part 2) 129
Instruction 130
131
Data 135
Data 136
Data 137
132
ROM 149
POST 150
BIOS 151
Bootstrap Loader 152
Operating System 153
Input Variables 154
155
156
157
Output Variables 161
162
163
164
Intermediate Variables 158
159
160
166
167
119
104
118
105
Interface 142
141
148
Reg. 144 (Instruction)
Reg. 145
Reg. 146 (Data)
Control Unit 139
ALU 140

Fig. 2

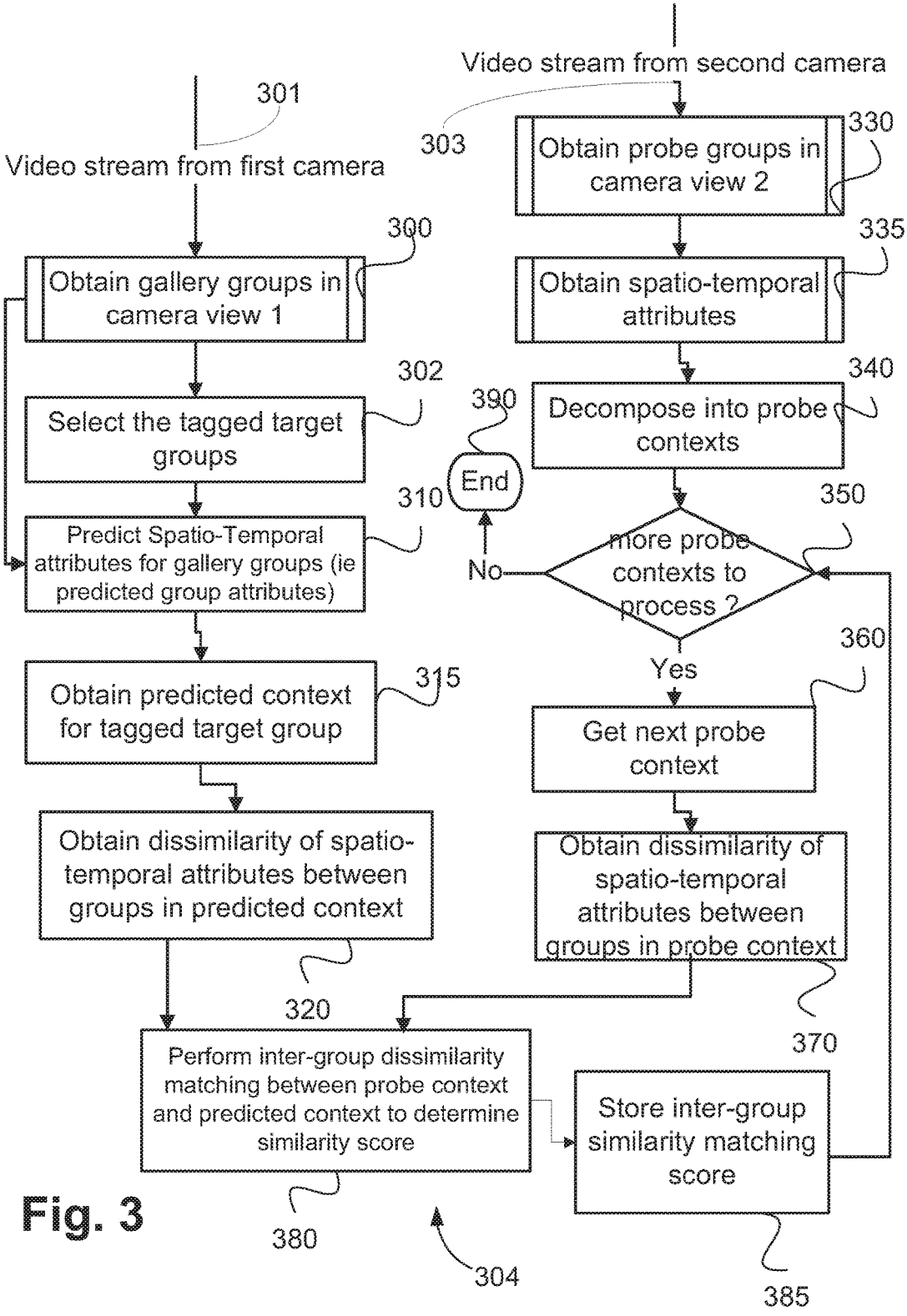
Video stream from second camera
301
303
Video stream from first camera
Obtain probe groups in camera view 2
330
300
335
Obtain gallery groups in camera view 1
Obtain spatio-temporal attributes
302
340
390
Select the tagged target groups
Decompose into probe contexts
End
310
350
Predict Spatio-Temporal attributes for gallery groups (ie predicted group attributes)
No
more probe contexts to process ?
360
Yes
315
Obtain predicted context for tagged target group
Get next probe context
Obtain dissimilarity of spatio-temporal attributes between groups in predicted context
Obtain dissimilarity of spatio-temporal attributes between groups in probe context
320
370
Perform inter-group dissimilarity matching between probe context and predicted context to determine similarity score
Store inter-group similarity matching score
380
304
385

Fig. 3

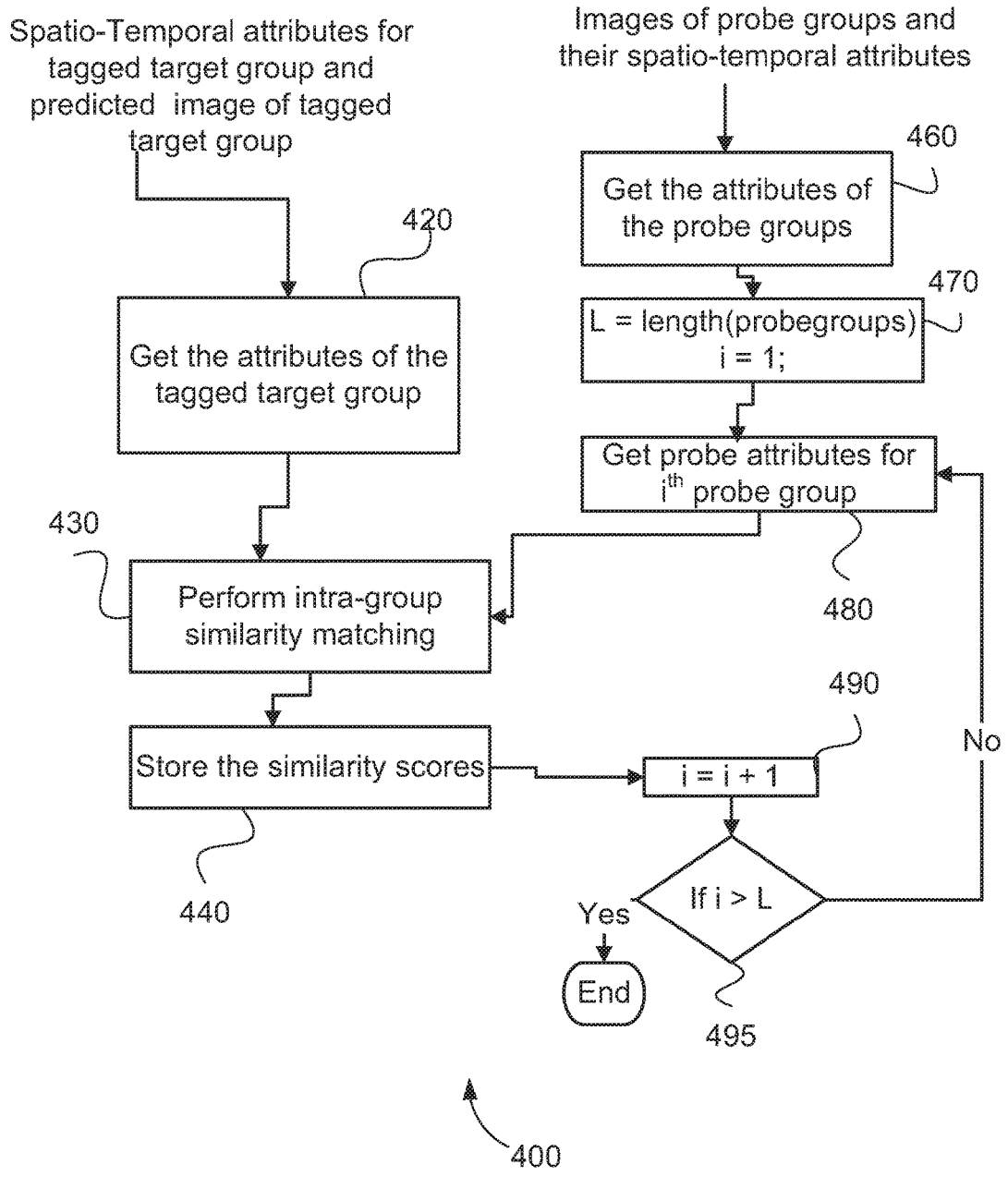
Spatio-Temporal attributes for tagged target group and predicted image of tagged target group
Images of probe groups and their spatio-temporal attributes
460
Get the attributes of the probe groups
420
Get the attributes of the tagged target group
470
L = length(probegroups)
i = 1;
Get probe attributes for i^th probe group
430
Perform intra-group similarity matching
480
490
Store the similarity scores
i = i + 1
No
440
If i > L
Yes
End
495
400

Fig. 4

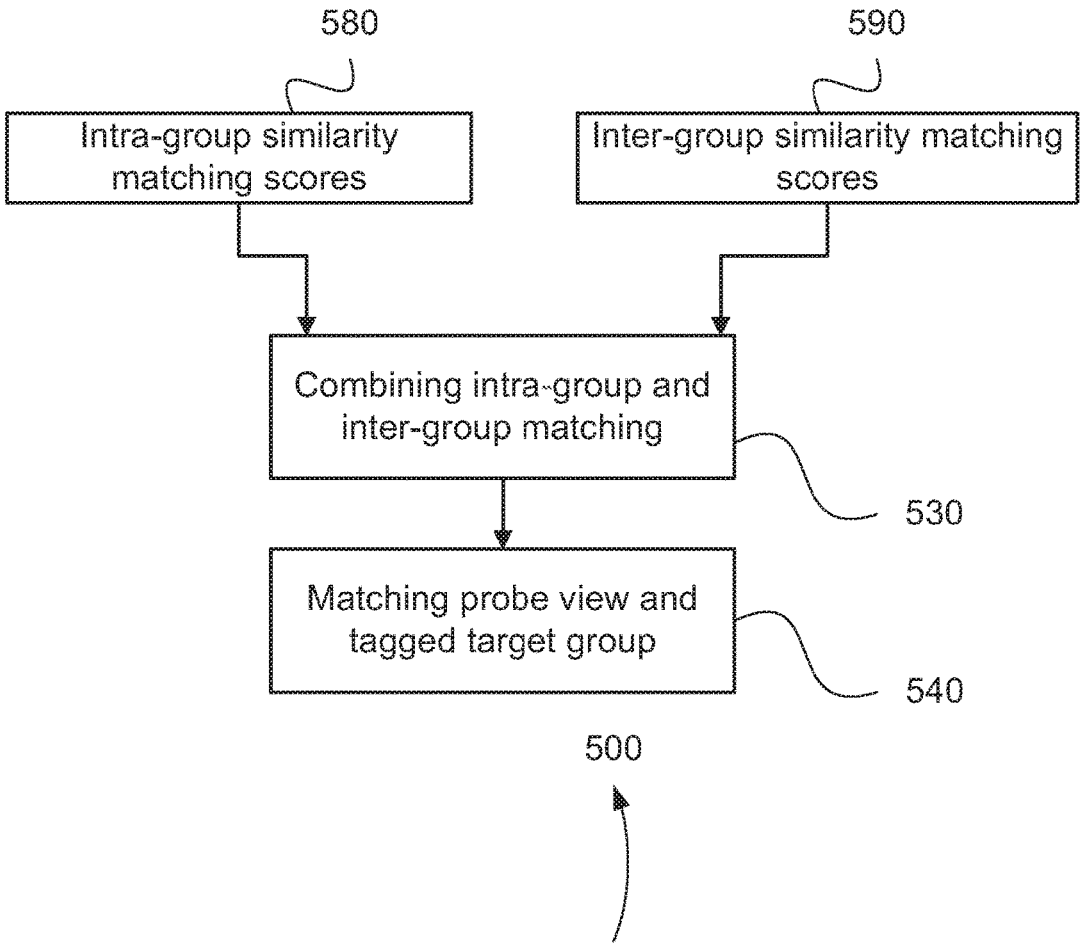
580
590
Intra-group similarity matching scores
Inter-group similarity matching scores
Combining intra-group and inter-group matching
530
Matching probe view and tagged target group
540
500

Fig. 5

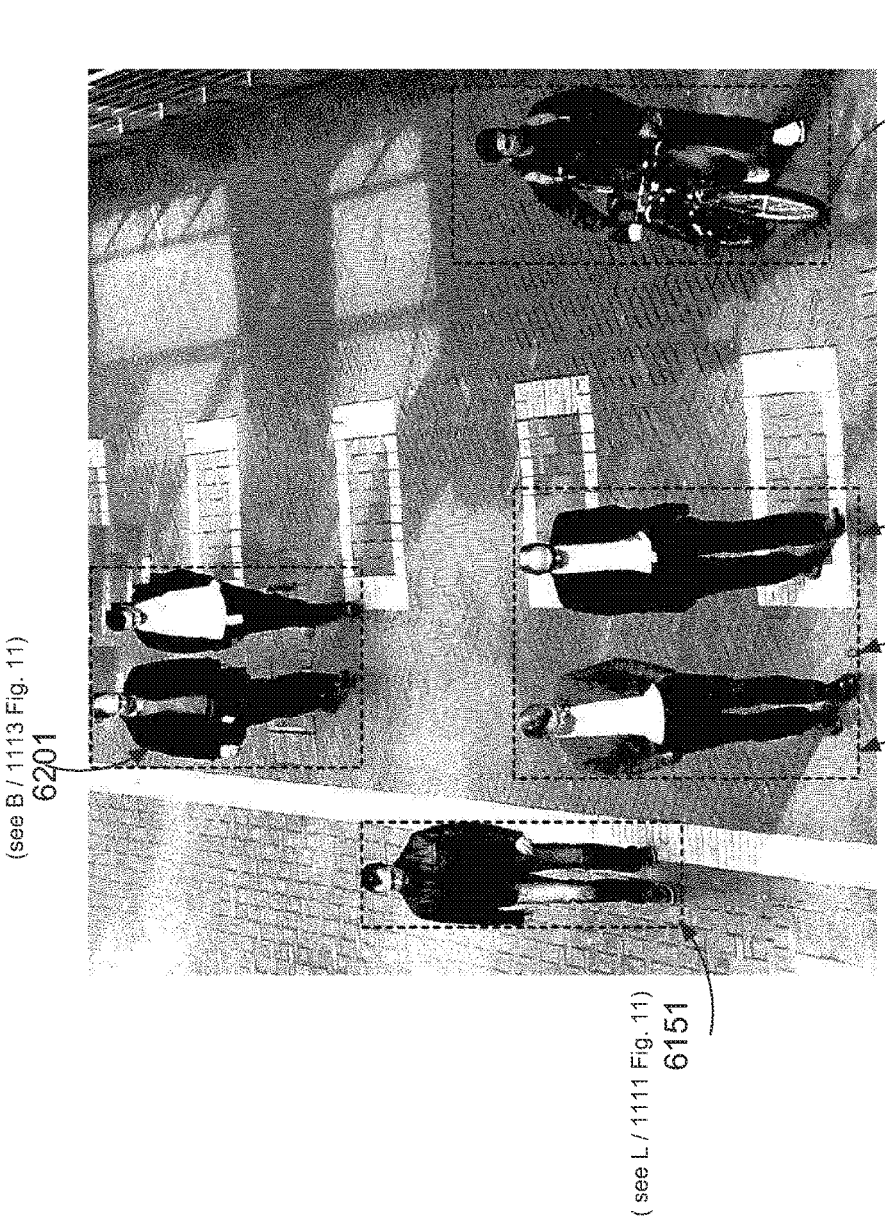
6101
(see C / 1112 Fig. 11)
6051
(see G / 1110 Fig. 11)
6251
6241
(see B / 1113 Fig. 11)
6201
(see L / 1111 Fig. 11)
6151

Fig. 6

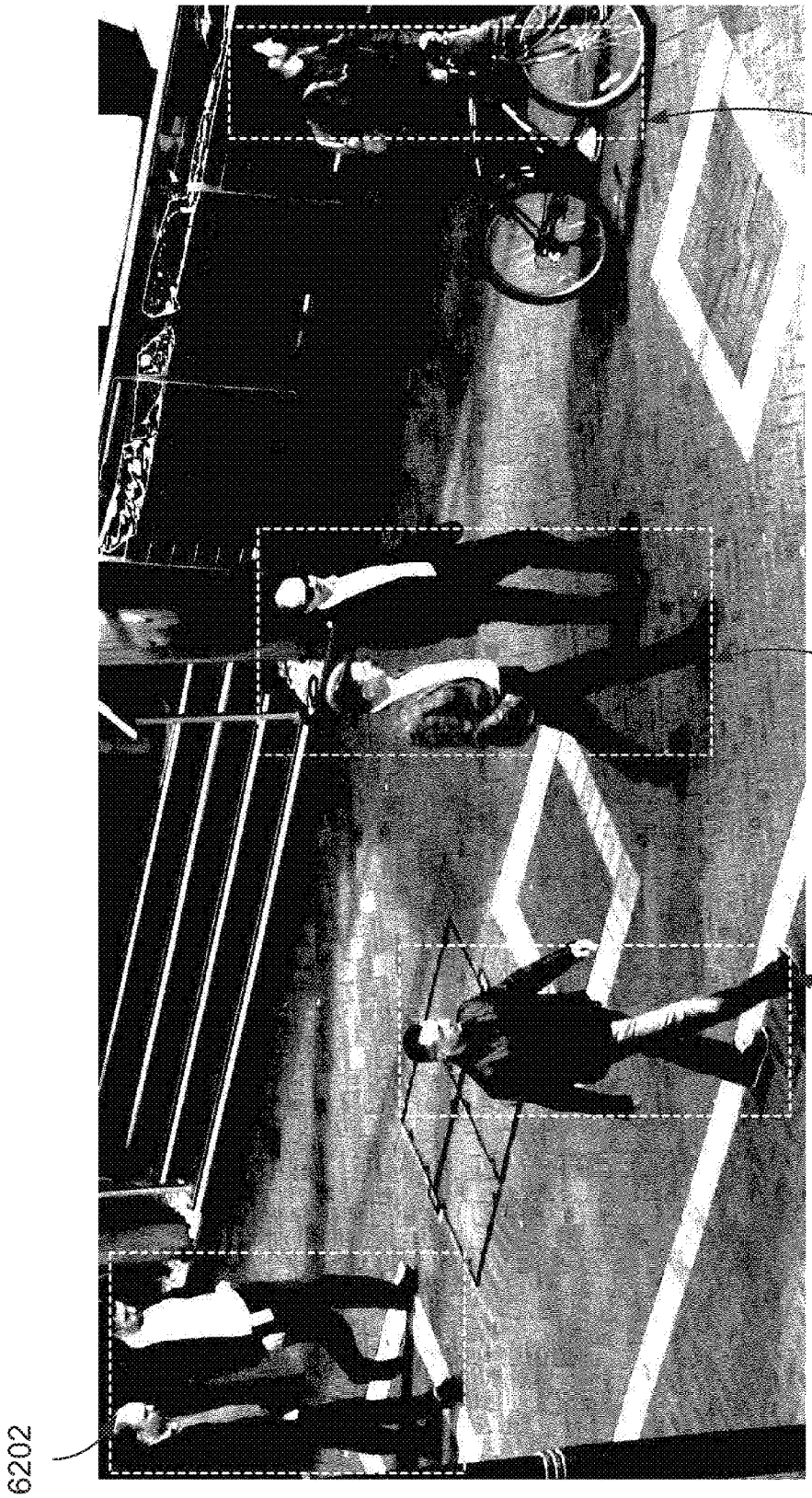

Fig. 7

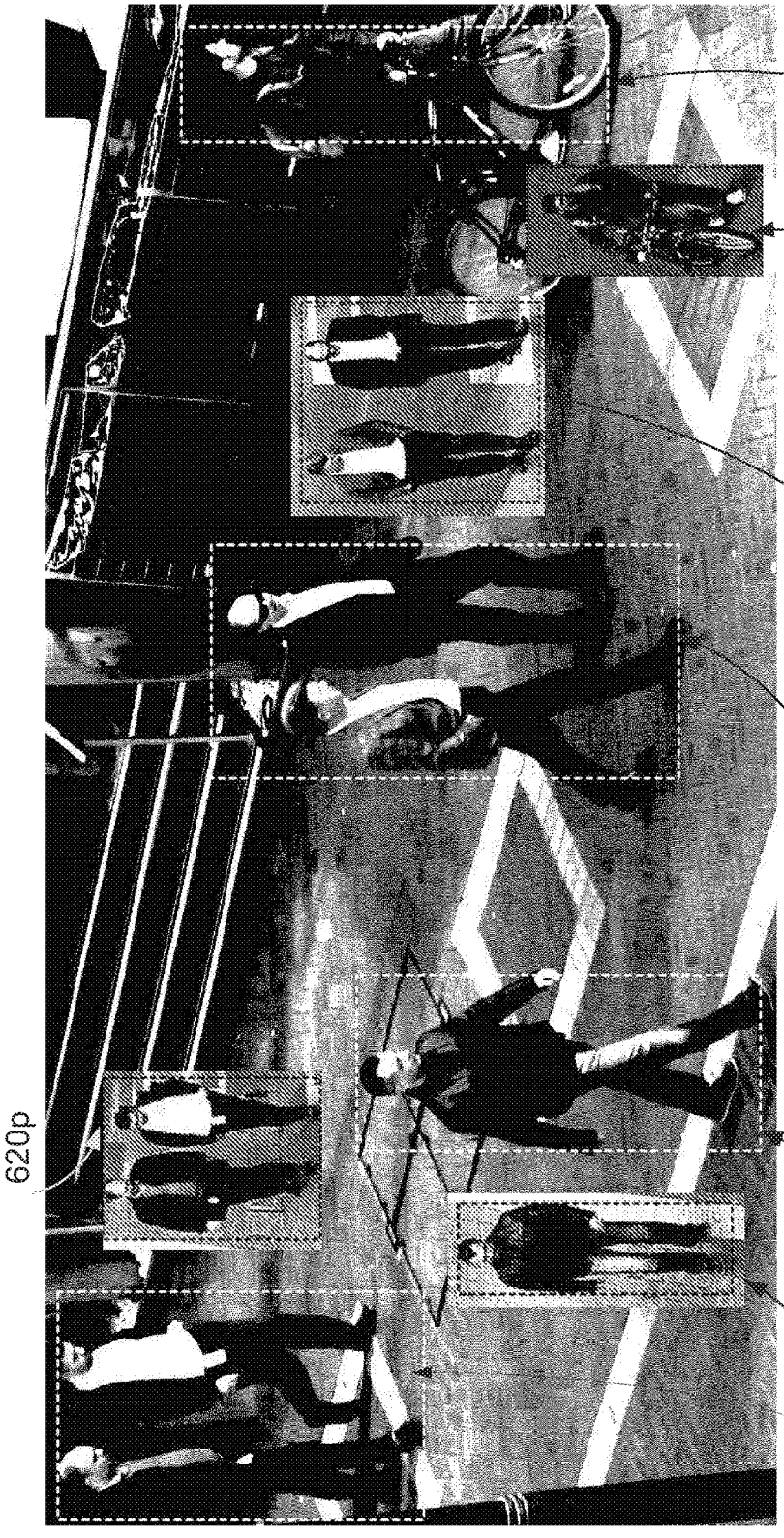

Fig. 8

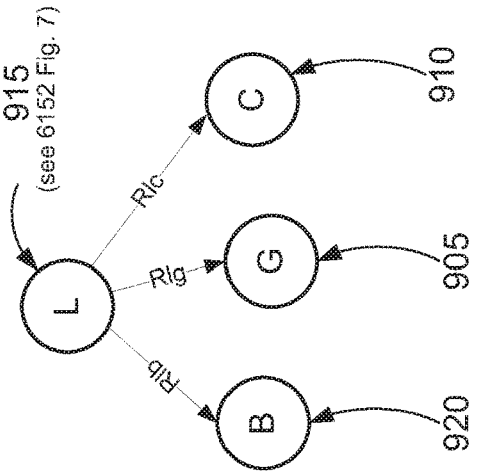

Fig. 9 (b)

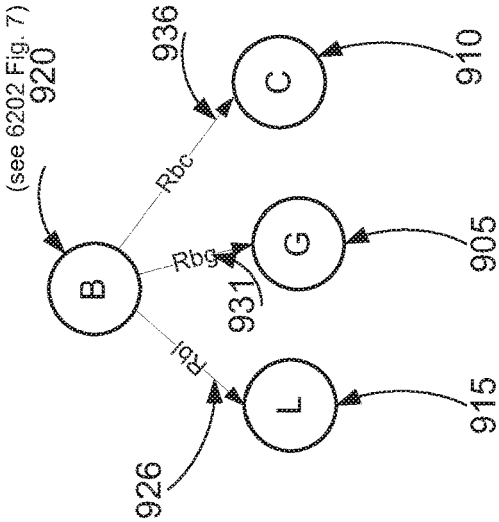

Fig. 9 (a)

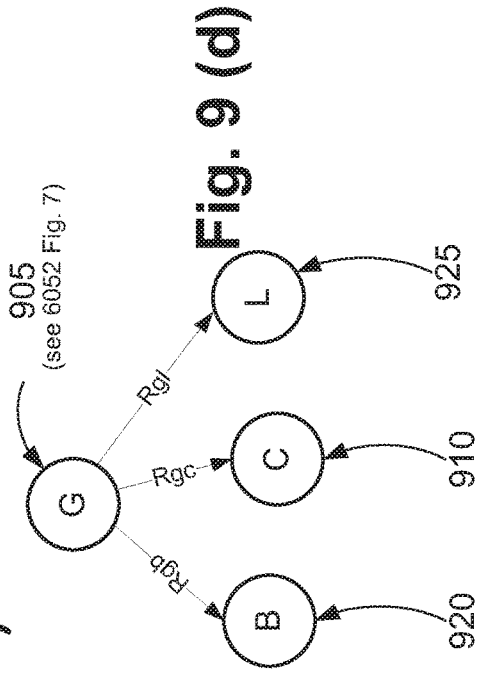

Fig. 9 (d)

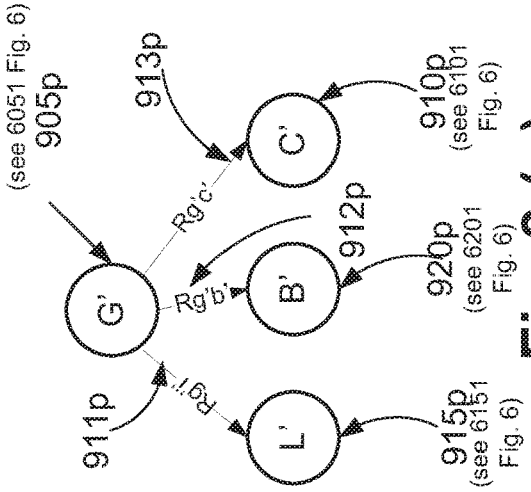

Fig. 9 (p)

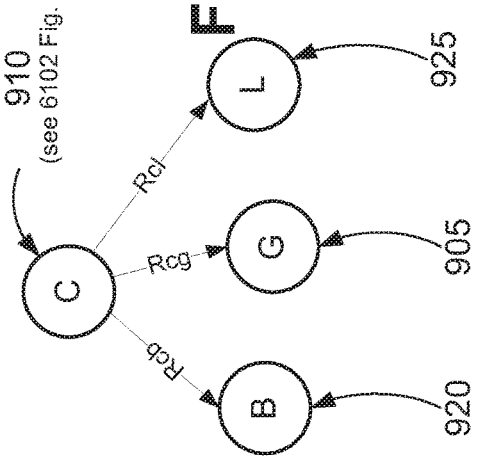

Fig. 9 (c)

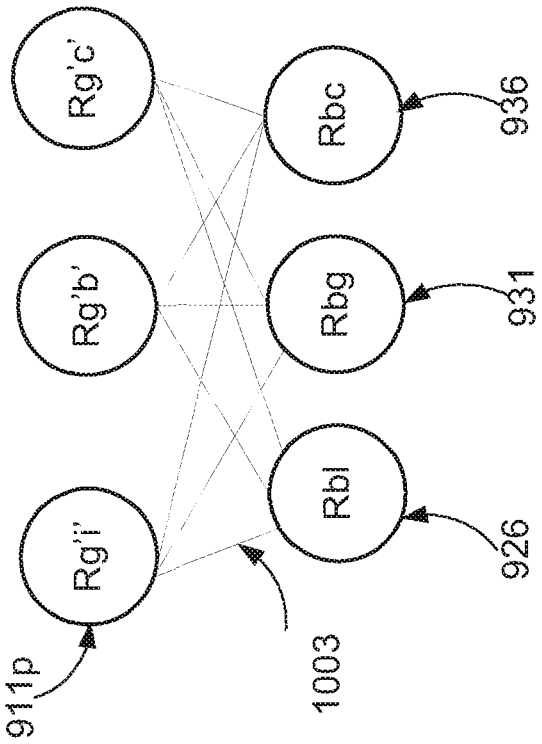

Fig. 10

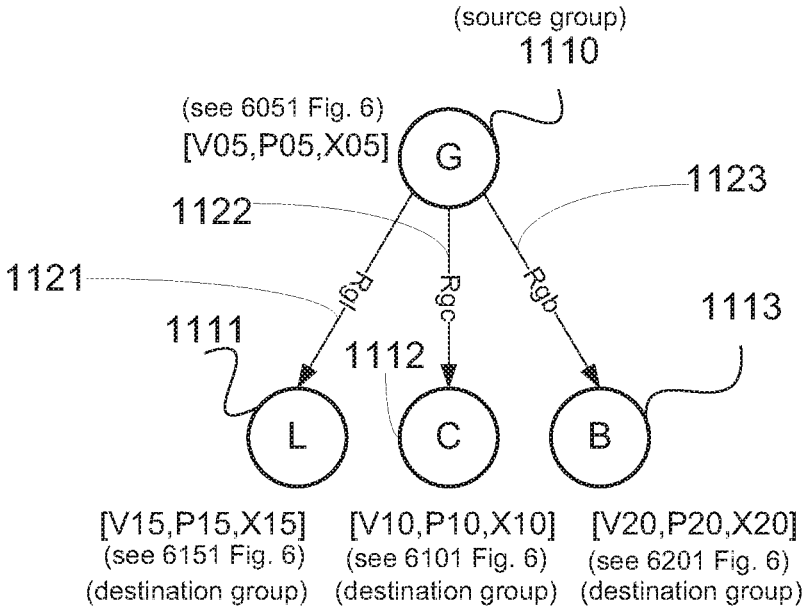
(source group)
1110
(see 6051 Fig. 6)
[V05,P05,X05]
G
1123
1122
1121
Rgl
Rgc
Rgb
1113
1111
1112
L
C
B
[V15,P15,X15]
(see 6151 Fig. 6)
(destination group)
[V10,P10,X10]
(see 6101 Fig. 6)
(destination group)
[V20,P20,X20]
(see 6201 Fig. 6)
(destination group)

Fig. 11

SYSTEM AND METHOD FOR OBJECT MATCHING

CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims the benefit of Australian Patent Application No. 2015-203591, filed Jun. 26, 2015, which is hereby incorporated by reference herein in its entirety.

TECHNICAL FIELD

The present invention relates to matching groups in visual images or video streams and, in particular, to matching groups of people across different camera views.

BACKGROUND

Public venues such as shopping centres, parking lots and train stations are increasingly subject to surveillance using large-scale networks of video cameras. Application domains of large-scale video surveillance include security, safety, traffic management and business analytics. In an example from the business analytics domain, a shopping centre may wish to track customers across multiple cameras in order to build a profile of shopping habits.

A key task in many of these applications is the performance of rapid and robust object matching across multiple camera views. In one example, also called "re-identification", object matching is used to locate a specific object of interest or specific objects of interest across multiple cameras in the network with non-overlapping fields of view.

Robust object matching is a challenging problem for several reasons. Firstly, many objects may have similar appearance, such as a crowd of commuters on public transport wearing similar business attire. Furthermore, the viewpoint (i.e. the orientation and distance of an object in the camera's field of view) can vary significantly between cameras in the network. Finally, lighting, shadows and other photometric properties including focus, contrast, brightness and white balance can vary significantly between cameras and locations. In one example, a single network may simultaneously include outdoor cameras viewing objects in bright daylight, and indoor cameras viewing objects under artificial lighting.

One approach to solving this problem is to use group matching for object re-identification. There are several approaches to group matching.

In one approach, appearance-based ratio-occurrence descriptors are used for matching group images. A Centre Rectangular Ring Ratio-Occurrence (CRRRO) defines a rectangular ring structure expanding from the centre of a group image, and Block-based ratio-occurrence (BRO) defines a block based structure where the entire image is divided into blocks. In both these cases, a colour histogram is extracted for the ring or block structure and used for comparison. CRRRO has the disadvantage that it cannot handle large non-centre-rotational changes in people's positions within a group.

In another approach, appearance-based covariance (COV) descriptors can be used for group matching. COV is a discriminative descriptor that captures both appearance and spatial properties of image regions.

Both the approaches have the disadvantage that they do not work when matching groups with similar appearance, for example where people are dressed in business suits.

Some methods adopt a Bayesian framework for consistent labelling across non-overlapping camera views. The Bayesian framework uses spatial-temporal cues (as priors) and visual appearance cues (as likelihoods) for computing a maximum-a-posteriori (MAP) estimator. In situations comprising multiple disjoint fields of view (FOVs), for a new detected object in one FOV, the Bayesian framework formulates a hypothesis space in another earlier FOV and assigns a higher prior to the objects composing a hypothesis if they enter the later FOV at the same time and a lower prior if they enter at different times. This approach has the disadvantage that the formulated hypothesis space is not scalable as it is likely to become very large and cause a very large computational overhead. In addition, this method relies more on low-level visual appearance cues.

In another approach, combining biometric cues such as gait and spatio-temporal cues such as velocity and position is used. This approach uses a graph to model people and their relationships in an input video stream. Each person is modelled as a node in the graph and there is an edge connecting two persons if they are spatially close to each other. The identity of each person is then propagated to their connected neighbours in the form of message passing in a graph via belief propagation. The message passed depends on a local evidence term capturing the biometric cue such as face or gait, and a compatibility term describing the spatio-temporal cue. This approach is complicated and inefficient, since it performs message passing on the underlying graph model.

In another method, for each track, an appearance context score is determined by summing weighted appearance similarity scores with its neighbours. Weights are determined by the closeness of the track's end times. To match between tracks of objects, an inter-object similarity score for two tracks in different views is obtained by subtracting the corresponding appearance context scores. The final appearance affinity score between the tracks is obtained by adding the inter-object similarity score and appearance similarity score. This approach relies heavily relies on low-level appearance which is not robust for identifying people with similar appearances in a view, or where appearance changes across views (e.g. caused by viewpoint and illumination changes). Also, this approach does not work well in the situation where neighbours change.

SUMMARY

It is an object of the present invention to substantially overcome, or at least ameliorate, one or more disadvantages of existing arrangements.

Disclosed are arrangements, referred to as Context Based Comparison (CBC) arrangements in this specification, which seek to address the above problems by matching attributes and relationships of a tagged target group in a first camera field of view against attributes and relationships of (candidate) groups in a second camera field of view, in order to identify the tagged target group in the second camera field of view.

According to a first aspect of the present invention, there is provided a computer implemented method of matching a tagged target group, selected from a plurality of gallery groups in a first camera field of view, with probe groups in a second camera field of view, the method comprising the steps of:

determining, by the computer, a group context for the tagged target group;

determining, by the computer, in the second camera field of view, probe contexts for the respective probe groups in the second camera field of view;

matching, by the computer, the group context against the probe contexts to produce respective similarity scores; and

identifying, by the computer, based upon the similarity scores, the probe group that matches the tagged target group.

Preferably, the step of determining a group context for the tagged target group comprises determining, in the second camera field of view, a predicted group context for the tagged target group.

Preferably, the group context and the probe context are dissimilarity contexts.

Optionally, the method further comprises the steps of:

determining appearance models for the tagged target group and the probe groups;

matching the appearance model of the tagged target group against the appearance models of the probe groups to produce respective intra-group similarity distance scores; and

identifying the probe group that matches the tagged target group based upon the intra-group similarity scores.

Optionally, the appearance model for the tagged target group is determined based upon the tagged target group in the field of view of the first camera.

Optionally, at least one of the predicted group context and the probe context are determined based upon filter criteria.

According to another aspect of the invention, there is provided an apparatus for matching a tagged target group, selected from a plurality of gallery groups in a first camera field of view, with probe groups in a second camera field of view, the apparatus comprising:

a memory storing a computer executable program; and

a processor for executing the program to perform a method comprising the steps of:

determining a group context for the tagged target group;

determining in the second camera field of view, probe contexts for the respective probe groups in the second camera field of view;

matching, by the computer, the group context against the probe contexts to produce respective similarity scores; and

identifying, by the computer, based upon the similarity scores, the probe group that matches the tagged target group.

According to another aspect of the invention, there is provided a computer readable non-transitory storage medium storing a computer executable program for directing a processor to perform, in an apparatus for matching a tagged target group selected from a plurality of gallery groups in a first camera field of view with probe groups in a second camera field of view, a method comprising the steps of:

determining a group context for the tagged target group;

determining in the second camera field of view, probe contexts for the respective probe groups in the second camera field of view;

matching, by the computer, the group context against the probe contexts to produce respective similarity scores; and

identifying, by the computer, based upon the similarity scores, the probe group that matches the tagged target group.

Other aspects of the invention are also disclosed.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the invention will now be described with reference to the following drawings, in which:

FIGS. **1** and **2** form a schematic block diagram of a general purpose computer system upon which the CBC arrangements can be implemented;

FIG. **3** is a flow diagram illustrating a CBC inter-group matching process;

FIG. **4** is a flow diagram illustrating a CBC intra-group matching process;

FIG. **5** is a the flow diagram which illustrates the process of combining intra-group matching with inter-group matching in a CBC arrangement;

FIG. **6** provides an illustration of a CBC arrangement, showing an example of a frame streamed from camera **1**;

FIG. **7** provides an illustration of a CBC arrangement, showing an example of the frame streamed from camera **2**;

FIG. **8** provides an illustration of a CBC arrangement, showing an example of the frame streamed from camera **2** along with predictions of camera **1**;

FIG. **9**, which includes FIGS. **9**(*a*)-**9**(*d*) and FIG. **9**(*p*), provides an illustration of a CBC arrangement, depicting a star graph representation to depict the predicted context for tagged target and the star graph representation for each of the probe groups.

FIG. **10** provides an illustration of a CBC arrangement, showing an example of a bipartite graph with the relationships of the predicted context and probe context as the nodes; and

FIG. **11** is an example of a context which is represented as a star graph for the scene in FIG. **6**.

DETAILED DESCRIPTION INCLUDING BEST MODE

Where reference is made in any one or more of the accompanying drawings to steps and/or features, which have the same reference numerals, those steps and/or features have for the purposes of this description the same function(s) or operation(s), unless the contrary intention appears.

It is to be noted that the discussions contained in the "Background" section relating to prior art arrangements relate to discussions of arrangements which may form public knowledge through their use. Such discussions should not be interpreted as a representation by the inventors or the patent applicant(s) that such arrangements in any way form part of the common general knowledge in the art.

The following terms, in bold italic format, are defined in this specification as indicated, unless explicitly defined differently.

context: representation of relationships between attributes of groups in a scene, as may be represented by a star graph or as a vector.

destination group: a group at the arrow end of a directed edge;

dissimilarity: representation of a difference relationship between two groups in a star graph (this may be represented by an edge in a star graph);

dissimilarity context; a context in which the edges represent the differences between the group attributes (also referred to simply as a context unless otherwise specified);

edge; represents relationships between two groups in a star graph (eg an edge may represent the dissimilarity between the attributes of the two groups);

entry time: the time a group enters the field of view (FOV) of a camera;

exit time: the time a group leaves the FOV of a camera;

gallery group: a group in the gallery view;

gallery view: a video stream from the FOV of a first camera;

group attributes: attributes of a group (such as [V, P, X] where V is the velocity of the group, P is the position of the group and X is the exit time of the group);

inter-group dissimilarity matching: a process of matching (i) each local probe dissimilarity context in the probe view and (ii) the predicted target group dissimilarity context in the probe view, or target group dissimilarity context in the gallery view, to produce a set of similarity scores;

local probe context: the context for a probe group;

node: represents attributes of a group in a star graph;

vector-context: Is the vector representation of a context. It is a vector which incorporates all the relationship attributes (eg all the edges) in the star graph, such as [Rgl Rgc Rgb], where Rgl is [V_{05}-V_{15}, P_{05}-P_{15}, X_{05}-X_{15}] etc;

predicted context: representation of the relationships between the attributes of a gallery group in the probe view;

predicted group: an image of a gallery group (as depicted in the gallery view) or predicted image of the gallery group in the probe view together with the predicted spatio-temporal attributes for the gallery group in the probe view;

probe group: a group in the probe view;

probe view: a video stream from the FOV of a second camera;

relationship attributes: attributes that represent a relationship between groups, for example a directed edge (ie a vector) in a star graph such as [V_{15}-V_{05}, P_{15}-P_{05}, X_{15}-X_{05}];

similarity score: a measure of how closely a particular local probe context matches the predicted target group context;

source group: a group at the opposite end of the directed edge from the arrow;

spatio-temporal attributes: attributes which relate to space and time, such as position, entry and exit time;

star graph: a representation of a context in which nodes represent attributes of groups, and edges represent relationships between the groups;

tagged target group: a gallery group to be identified in the probe view;

The present disclosure is directed towards providing a technique of group matching across different camera views as a means of group re-identification. The CBC arrangements involve determining the similarity between contexts (eg see a step **380** in FIG. **3**). This specification describes the determination of similarity where the contexts in question are dissimilarity contexts, ie where the directed edges in the star graphs representing the context represent the differences between the group attributes. However, the CBC arrangements are not limited to edges of this form. The contexts referred to in this specification are thus dissimilarity context unless otherwise specified.

The disclosed CBC arrangements help to match groups across different overlapping or non-overlapping camera fields of view. A group consists of one of more people or objects such as cars. A group may be a social group like family or friends, or an accidental group which is formed dynamically based upon attributes such as spatio-temporal attributes.

Spatio-temporal attributes are attributes which relate to space and time, such as position, entry and exit time. A position (such as **6251**) of a group (such as **6051**) can, in one CBC arrangement, be defined as the ground plane co-ordinates of a midpoint of a lower edge of a bounding box for the group in question, where the bounding box is a 2-D rectangle (such as **6241**) around the group members as illustrated in FIG. **6**. An entry time is the time a group enters the field of view of a camera. An exit time is the time a group leaves the field of view of a camera.

Let us consider a scenario of two non-overlapping cameras. A first video stream obtained from the first camera is referred to as the gallery view. The gallery view is made up of one or more frames of the first video stream. Groups in the gallery view are referred to as gallery groups. A second video stream obtained from the second camera is the referred to as the probe view. The probe view is made up of one or more frames of the second video stream. Groups formed in the probe view are the probe groups. A tagged target group is a gallery group (ie in the gallery view) which is designated as needing to be identified in the probe view. There may be one or more tagged target groups. The tagged target group may be pre-defined, or may be selected using a user interface such as the keyboard **102**, or may be identified by using a description such as the group with "two people wearing white shirts".

The term context is defined as the relationship between the attributes of the groups in a scene.

In one CBC implementation, all the groups in the scene are considered when defining context.

In another CBC implementation, a filtered neighbourhood, in which only certain groups are considered as the basis for defining context, based on filtering criteria such as their relationship to the tagged target group, their behaviour or their position in the scene. For example, groups that are close to the tagged target group may be considered as a filtered neighbourhood and groups at the periphery of the scene may not be considered.

Context is similar to a higher space which defines all the different types of relationships between group attributes in a scene.

Examples of attributes are spatio-temporal attributes such as velocity, position, entry time, exit time, distance, appearance attributes such as appearance colour features or Histogram of Oriented Gradients (HOG) features. The velocity of a group is obtained by tracking the position of a group over time. For example, the group attributes of a node **1110** which represents the group **6051** (see FIG. **11**) are [V_{05}, P_{05}, X_{05}] where V_{05} is the velocity of the group, P_{05} is the position of the group and X_{05} is the exit time of the group.

In one CBC implementation, the context of a group is represented as a star graph (described hereinafter in more detail with reference to FIG. **11**) where nodes represent attributes of groups, and edges represent relationships between the groups. Attributes of the group may be spatio-temporal attributes or appearance attributes. The attributes of the groups are called group attributes. The edges, which represent the relationship between the groups, in one CBC implementation may be the difference (also referred to as dissimilarity) between the attributes. A context in which the edges are the difference (ie the dissimilarity) between the group attributes is referred to as a dissimilarity context. Attributes that represent the relationship between the groups are called relationship attributes.

FIG. **11** is an example of a context which is represented as a star graph for the scene in FIG. **6**.

In FIG. **11**, the groups **6201**, **6151**, **6051** and **6101** have respective group attributes [V_{20}, P_{20}, X_{20}], [V_{15}, P_{15}, X_{15}], [V_{05}, P_{05}, X_{05}], [V_{10}, P_{10}, X_{10}] where V is the velocity of the corresponding group, P is the position of the corresponding group and X is the exit time of the corresponding group. In the star graph shown in FIG. **11** the group **6051** is represented by a node **1110** (ie G). Similarly **6151** is represented by a node **1111** (ie L), **6101** is represented by a node **1112** (ie C) and **6201** is represented by a node **1113** (ie B). Each

node has respective group attributes. For example, the node **1110** has the attributes for group **6051** which are [V_{05}, P_{05}, X_{05}].

Edges represent relationship between the groups. In some CBC implementations, edges can be directed edges. For example, an edge Rgl (ie **1121**) represents the relationship between the groups G and L. In one CBC implementation, an edge represents the dissimilarity between the attributes of the respective groups. For example, taking the difference between the attributes of the groups, in one CBC implementation gives the dissimilarity between the groups. For example Rgl (ie **1121**) is a vector (ie a directed edge) with attribute value [V_{15}-V_{05}, P_{15}-P_{05}, X_{15}-X_{05}]. If the edge is a directed edge, it represents destination group (ie the group at the arrow end of the directed edge) attributes minus the source group (ie the group at the opposite end of the directed edge from the arrow) attributes. For example the relationship Rgl has relationship attributes which are the group L attributes minus group G attributes. Similarly, Rgc (ie **1122**) gives the relationship between groups G and C and Rgb (ie **1123**) gives the relationship between groups G and B.

The context in one example is represented as a vector which incorporates all the relationship attributes in the star graph. For example, O is the vector-context (vector representation of context) for FIG. **11** and can be expressed as follows:

$$O=[Rgl\ Rgc\ Rgb]$$

where Rgl is [V_{15}-V_{05}, P_{15}-P_{05}, X_{15}-X_{05}], Rgc is [V_{10}-V_{05}, P_{10}-P_{05}, X_{10}-X_{05}] and Rgb is [V_{20}-V_{05}, P_{20}-P_{05}, X_{20}-X_{05}]. The vector representation of the context is a vector-context.

The context, which in one example is referred to as the dissimilarity of attributes of groups in a scene, can be regarded as a signature of the groups in question.

It is noted that O as described above is the vector-context depicted in FIG. **11** with the node G designated as the source group, and the nodes L, C and B designated as destination groups.

Inter-Group Matching

As described hereinafter in more detail with reference to FIGS. **3-11**, FIGS. **1** and **2** depict a general-purpose computer system **100**, upon which the various CBC arrangements described can be practiced.

As seen in FIG. **1**, the computer system **100** includes: a computer module **101**; input devices such as a keyboard **102**, a mouse pointer device **103**, a scanner **126**, a camera **127**, and a microphone **180**; and output devices including a printer **115**, a display device **114** and loudspeakers **117**. An external Modulator-Demodulator (Modem) transceiver device **116** may be used by the computer module **101** for communicating to and from a communications network **120** via a connection **121**. The communications network **120** may be a wide-area network (WAN), such as the Internet, a cellular telecommunications network, or a private WAN. Where the connection **121** is a telephone line, the modem **116** may be a traditional "dial-up" modem. Alternatively, where the connection **121** is a high capacity (e.g., cable) connection, the modem **116** may be a broadband modem. A wireless modem may also be used for wireless connection to the communications network **120**.

The computer module **101** typically includes at least one processor unit **105**, and a memory unit **106**. For example, the memory unit **106** may have semiconductor random access memory (RAM) and semiconductor read only memory (ROM). The computer module **101** also includes an number of input/output (I/O) interfaces including: an audio-video interface **107** that couples to the video display **114**, loudspeakers **117** and microphone **180**; an I/O interface **113** that couples to the keyboard **102**, mouse **103**, scanner **126**, camera **127** and optionally a joystick or other human interface device (not illustrated); and an interface **108** for the external modem **116** and printer **115**. In some implementations, the modem **116** may be incorporated within the computer module **101**, for example within the interface **108**. The computer module **101** also has a local network interface **111**, which permits coupling of the computer system **100** via a connection **123** to a local-area communications network **122**, known as a Local Area Network (LAN). As illustrated in FIG. **1**, the local communications network **122** may also couple to the wide network **120** via a connection **124**, which would typically include a so-called "firewall" device or device of similar functionality. The local network interface **111** may comprise an Ethernet circuit card, a Bluetooth® wireless arrangement or an IEEE 802.11 wireless arrangement; however, numerous other types of interfaces may be practiced for the interface **111**.

The I/O interfaces **108** and **113** may afford either or both of serial and parallel connectivity, the former typically being implemented according to the Universal Serial Bus (USB) standards and having corresponding USB connectors (not illustrated). Storage devices **109** are provided and typically include a hard disk drive (HDD) **110**. Other storage devices such as a floppy disk drive and a magnetic tape drive (not illustrated) may also be used. An optical disk drive **112** is typically provided to act as a non-volatile source of data. Portable memory devices, such optical disks (e.g., CD-ROM, DVD, Blu ray Disc™), USB-RAM, portable, external hard drives, and floppy disks, for example, may be used as appropriate sources of data to the system **100**.

The components **105** to **113** of the computer module **101** typically communicate via an interconnected bus **104** and in a manner that results in a conventional mode of operation of the computer system **100** known to those in the relevant art. For example, the processor **105** is coupled to the system bus **104** using a connection **118**. Likewise, the memory **106** and optical disk drive **112** are coupled to the system bus **104** by connections **119**. Examples of computers on which the described arrangements can be practised include IBM-PC's and compatibles, Sun Sparcstations, Apple Mac™ or like computer systems.

The CBC arrangements may be implemented using the computer system **100** wherein the processes of FIGS. **3-5**, to be described, may be implemented as one or more software application programs **133** executable within the computer system **100**. In particular, the steps of the CBC method are effected by instructions **131** (see FIG. **2**) in the software **133** that are carried out within the computer system **100**. The software instructions **131** may be formed as one or more code modules, each for performing one or more particular tasks. The software may also be divided into two separate parts, in which a first part and the corresponding code modules performs the CBC methods and a second part and the corresponding code modules manage a user interface between the first part and the user.

The software may be stored in a computer readable medium, including the storage devices described below, for example. The software is loaded into the computer system **100** from the computer readable medium, and then executed by the computer system **100**. A computer readable medium having such software or computer program recorded on the computer readable medium is a computer program product. The use of the computer program product in the computer system **100** preferably effects an advantageous CBC apparatus.

The software **133** is typically stored in the HDD **110** or the memory **106**. The software is loaded into the computer system **100** from a computer readable medium, and executed by the computer system **100**. Thus, for example, the software **133** may be stored on an optically readable disk storage medium (e.g., CD-ROM) **125** that is read by the optical disk drive **112**. A computer readable medium having such software or computer program recorded on it is a computer program product. The use of the computer program product in the computer system **100** preferably effects a CBC apparatus.

In some instances, the application programs **133** may be supplied to the user encoded on one or more CD-ROMs **125** and read via the corresponding drive **112**, or alternatively may be read by the user from the networks **120** or **122**. Still further, the software can also be loaded into the computer system **100** from other computer readable media. Computer readable storage media refers to any non-transitory tangible storage medium that provides recorded instructions and/or data to the computer system **100** for execution and/or processing. Examples of such storage media include floppy disks, magnetic tape, CD-ROM, DVD, Blu-ray™ Disc, a hard disk drive, a ROM or integrated circuit, USB memory, a magneto-optical disk, or a computer readable card such as a PCMCIA card and the like, whether or not such devices are internal or external of the computer module **101**. Examples of transitory or non-tangible computer readable transmission media that may also participate in the provision of software, application programs, instructions and/or data to the computer module **101** include radio or infra-red transmission channels as well as a network connection to another computer or networked device, and the Internet or Intranets including e-mail transmissions and information recorded on Websites and the like.

The second part of the application programs **133** and the corresponding code modules mentioned above may be executed to implement one or more graphical user interfaces (GUIs) to be rendered or otherwise represented upon the display **114**. Through manipulation of typically the keyboard **102** and the mouse **103**, a user of the computer system **100** and the application may manipulate the interface in a functionally adaptable manner to provide controlling commands and/or input to the applications associated with the GUI(s). Other forms of functionally adaptable user interfaces may also be implemented, such as an audio interface utilizing speech prompts output via the loudspeakers **117** and user voice commands input via the microphone **180**.

FIG. **2** is a detailed schematic block diagram of the processor **105** and a "memory" **134**. The memory **134** represents a logical aggregation of all the memory modules (including the HDD **109** and semiconductor memory **106**) that can be accessed by the computer module **101** in FIG. **1**.

When the computer module **101** is initially powered up, a power-on self-test (POST) program **150** executes. The POST program **150** is typically stored in a ROM **149** of the semiconductor memory **106** of FIG. **1**. A hardware device such as the ROM **149** storing software is sometimes referred to as firmware. The POST program **150** examines hardware within the computer module **101** to ensure proper functioning and typically checks the processor **105**, the memory **134** (**109**, **106**), and a basic input-output systems software (BIOS) module **151**, also typically stored in the ROM **149**, for correct operation. Once the POST program **150** has run successfully, the BIOS **151** activates the hard disk drive **110** of FIG. **1**. Activation of the hard disk drive **110** causes a bootstrap loader program **152** that is resident on the hard disk drive **110** to execute via the processor **105**. This loads an operating system **153** into the RAM memory **106**, upon which the operating system **153** commences operation. The operating system **153** is a system level application, executable by the processor **105**, to fulfil various high level functions, including processor management, memory management, device management, storage management, software application interface, and generic user interface.

The operating system **153** manages the memory **134** (**109**, **106**) to ensure that each process or application running on the computer module **101** has sufficient memory in which to execute without colliding with memory allocated to another process. Furthermore, the different types of memory available in the system **100** of FIG. **1** must be used properly so that each process can run effectively. Accordingly, the aggregated memory **134** is not intended to illustrate how particular segments of memory are allocated (unless otherwise stated), but rather to provide a general view of the memory accessible by the computer system **100** and how such is used.

As shown in FIG. **2**, the processor **105** includes a number of functional modules including a control unit **139**, an arithmetic logic unit (ALU) **140**, and a local or internal memory **148**, sometimes called a cache memory. The cache memory **148** typically includes a number of storage registers **144-146** in a register section. One or more internal busses **141** functionally interconnect these functional modules. The processor **105** typically also has one or more interfaces **142** for communicating with external devices via the system bus **104**, using a connection **118**. The memory **134** is coupled to the bus **104** using a connection **119**.

The application program **133** includes a sequence of instructions **131** that may include conditional branch and loop instructions. The program **133** may also include data **132** which is used in execution of the program **133**. The instructions **131** and the data **132** are stored in memory locations **128**, **129**, **130** and **135**, **136**, **137**, respectively. Depending upon the relative size of the instructions **131** and the memory locations **128-130**, a particular instruction may be stored in a single memory location as depicted by the instruction shown in the memory location **130**. Alternately, an instruction may be segmented into a number of parts each of which is stored in a separate memory location, as depicted by the instruction segments shown in the memory locations **128** and **129**.

In general, the processor **105** is given a set of instructions which are executed therein. The processor **105** waits for a subsequent input, to which the processor **105** reacts to by executing another set of instructions. Each input may be provided from one or more of a number of sources, including data generated by one or more of the input devices **102**, **103**, data received from an external source across one of the networks **120**, **102**, data retrieved from one of the storage devices **106**, **109** or data retrieved from a storage medium **125** inserted into the corresponding reader **112**, all depicted in FIG. **1**. The execution of a set of the instructions may in some cases result in output of data. Execution may also involve storing data or variables to the memory **134**.

The disclosed CBC arrangements use input variables **154**, which are stored in the memory **134** in corresponding memory locations **155**, **156**, **157**. The CBC arrangements produce output variables **161**, which are stored in the memory **134** in corresponding memory locations **162**, **163**, **164**. Intermediate variables **158** may be stored in memory locations **159**, **160**, **166** and **167**.

Referring to the processor **105** of FIG. **2**, the registers **144**, **145**, **146**, the arithmetic logic unit (ALU) **140**, and the control unit **139** work together to perform sequences of

micro-operations needed to perform "fetch, decode, and execute" cycles for every instruction in the instruction set making up the program **133**. Each fetch, decode, and execute cycle comprises:

- a fetch operation, which fetches or reads an instruction **131** from a memory location **128**, **129**, **130**;
- a decode operation in which the control unit **139** determines which instruction has been fetched; and
- an execute operation in which the control unit **139** and/or the ALU **140** execute the instruction.

Thereafter, a further fetch, decode, and execute cycle for the next instruction may be executed. Similarly, a store cycle may be performed by which the control unit **139** stores or writes a value to a memory location **132**.

Each step or sub-process in the processes of FIGS. **3-5** is associated with one or more segments of the program **133** and is performed by the register section **144**, **145**, **147**, the ALU **140**, and the control unit **139** in the processor **105** working together to perform the fetch, decode, and execute cycles for every instruction in the instruction set for the noted segments of the program **133**.

The CBC methods may alternatively be implemented in dedicated hardware such as one or more integrated circuits performing the CBC functions or sub functions. Such dedicated hardware may include graphic processors, digital signal processors, or one or more microprocessors and associated memories.

FIG. **3** shows a flow diagram illustrating a CBC inter-group matching process **304** performed by the processor **105** executing the CBC software **133** in order to match probe groups in the second camera view (probe view) with a tagged target group in the first camera view (gallery view). The inputs to the process **304** are low or high resolution images of a JPEG first video stream **301** from the first camera, and also low or high resolution images of the JPEG second video stream **303** from the second camera.

The JPEG images from the first video stream **301** of the first camera are passed as input to a step **300** and JPEG images from the second video stream **303** of the second camera are passed as input to a step **330**. The steps **300** and **330** process the JPEG images to respectively form gallery groups of people (eg **6201**, **6151**, **6051**, and **6101**) in the first camera field of view and probe groups of people (eg **6202**, **6152**, **6052** and **6102**) in the second camera field of view.

In one CBC implementation, groups may be pre-defined social groups who may be registered in the CBC system. For example, a family groups and a friends group may indicate beforehand that they are each one group, and consequently when they appear in the camera views they are automatically defined as a group. In another CBC implementation, accidental groups may be formed by considering the proximity of people or objects. For example, people or cars that satisfy a Euclidean distance threshold such as 20 pixels may be grouped together. Furthermore, people or vehicles that move with a similar velocity, such as 5 kms/hr, may be grouped together. In addition, people or objects that move in the same direction, such as travelling North, may be grouped together. In another CBC implementation, people or objects which meet all the combinations of criteria such as direction, velocity and proximity may be grouped together.

All groups formed by the steps **300**, **330** are assigned group identifier by the steps **300**, **330**, for example a numeric number such as 1.

Considering the gallery view, from the step **300**, control then passes to a step **302**. One or more tagged target group(s) are selected at this step. In one CBC implementation, the tagged target group(s) may be identified by control signal(s) from the user via a user interface such as the keyboard **102**, by means of which the user selects one or more groups of interest by entering the group identifier such as number **2**, or a description of the group such as "group with 2 people with white shirts". The user may also use the mouse **103** to point to the groups of interest in the gallery view that need to be identified in the probe view. The selected tagged target group identifiers from the step **302**, the image of the tagged target group(s) and the gallery groups and their attributes such as their appearance and spatio-temporal attributes from step **300** are passed to a following step **310**.

The step **310** predicts spatio-temporal attributes for gallery groups such as **6201**, in the second camera field of view, as depicted by **620***p* in FIG. **8**. The gallery groups are groups identified in the first camera field of view as depicted in FIG. **6**.

FIG. **8** shows an image **620***p* in the second camera FOV, where **620***p* is the predicted group associated with the gallery group **6201** in the first camera FOV. The predicted group **620***p* in FIG. **8** is the predicted image together with the predicted spatio-temporal attributes for the gallery group **6201**.

The prediction determines the spatio-temporal attributes of all the gallery groups in the second or probe camera field of view. Prediction is based on the spatio-temporal attributes of the gallery groups in the first camera field of view, the topology of the cameras and the distance between the cameras. Spatio-temporal attributes are attributes which relate to space and time parameters such as position, entry and exit time. An Entry time is the time a group enters the field of view of the camera in question. The entry time can be expressed as a frame number such as 1278, or as a time such as 12:20:01 (hh:mm:ss). An exit time is the time a group leaves the field of view of the camera in question.

In one CBC implementation, the prediction of the entry time of each of the gallery groups into the field of view of the 2^{nd} camera (ie the probe view) is performed by considering the exit time of the group in question from the gallery FOV, the velocity of the group and the distance between the cameras using the following formula:

predicted_entry_time_*c*2=exit_time_*c*1+distance/velocity

Prediction of the position of a group is performed by considering the x (x1) and y (y1) positions of the group in the last frame of the first camera FOV when the group exits the first camera FOV and the topology of the second camera and its FOV. If for example the topology of the cameras indicates that the cameras are in a straight line (in the x direction) and that people are walking in the y direction, then the x (x1) position of a group in the first camera FOV will be the x (x2) position of the group in the second camera FOV, the being expressed as follows:

x2=x1:−x positions of the two groups across cameras is the same

and the y position of the group in the second camera FOV y2 is expressed as follows:

*y*2=*y*1+distance_between_cameras:−translated *y* value based *on* the distance between the cameras

In another CBC implementation, in order to predict the velocity and position of a group from the first FOV in the second FOV, a training dataset is used. In one CBC implementation, a training dataset of training groups of people moving between the cameras is captured together with their attributes. Such attributes can include training groups' velocity, x and y positions in the first camera FOV, the time

at which the group exits the FOV of the first camera, and x and y positions in the second camera FOV when the group enters the FOV of the second camera. Training may be performed by using a machine learning algorithm such as Support Vector Machine (SVM). This machine learning algorithm can be applied to the training dataset, and consequently the x and y positions in the second camera FOV can be learned, given the x and y positions in the first camera FOV and the velocity of the group. This can be used in the step **310** to predict the position and the velocity of the group in the second camera FOV given the groups velocity and the position in the first camera FOV.

In another CBC implementation, the velocity at the exit time of a group in the first camera FOV may be used as the velocity of the group at the entry time of the second camera FOV.

The output of the step **310** is the predicted spatio-temporal attributes, in the second camera FOV, for each gallery group in the first camera FOV. Each of the gallery groups (ie their images) together with their predicted attributes, is referred to as a predicted group. For example, the image(s) of the tagged target group together with the predicted attributes, in the second camera FOV, is referred to as the predicted tagged target group.

Control then passes to a step **315**. This step determines the context of the predicted tagged target group. In one example, the step **315** represents the context of the predicted tagged target group as a context star graph, previously described with reference to FIG. **11**, in which the tagged target group is the source group, and the other gallery groups are the destination groups.

It is noted that the attributes of the predicted groups can include the spatio-temporal attributes of the predicted groups and may also include the appearance attributes of the predicted groups. The context star graph FIG. **11** utilizes nodes to represent groups and uses edges to represent relationships between the groups. The output of the step **315** is the output of the predicted context. In one CBC arrangement, this is a vector-context, which is a vector of the relationship attributes between the different groups. The vector incorporates all the relationship attributes in the star graph. For example for FIG. **11** the vector-context can be expressed as [Rgl Rgc Rgb] where Rgl is [V_{15}-V_{05}, P_{15}-P_{05}, X_{15}-X_{05}], Rgc is [V_{10}-V_{05}, P_{10}-P_{05}, X_{10}-X_{05}] and Rgb is [V_{20}-V_{05}, P_{20}-P_{05}, X_{20}-X_{05}].

Control then passes to a step **320**. This step may firstly determine a subset of the relationship attributes in the predicted context, depending on the scene. For example, if the scene has many groups with similar appearances, then spatio-temporal attributes are considered. Otherwise, other attributes such as appearance or the number of people in groups are considered.

The step **320** then determines spatio-temporal dissimilarity attributes (or other dissimilarity attributes depending upon the attributes being considered) which describe the dissimilarity between the tagged target group (as the source group) in the predicted context, and each of the other gallery groups (as destination groups) in the predicted context. The output of the step **320** is the relationship attributes which describe the spatio-temporal attributes between the tagged target group, and the other gallery groups in the predicted context. It is noted that the output of the step **315** can include attributes such as spatio-temporal, appearance etc. The output of the step **320** however is considering only a subset of attributes, in this case only spatio-temporal.

In one CBC implementation, relationship attributes can be defined as a vector of attributes (also referred to as an attribute vector) such as [v, e, x, p] where v is the velocity, e entry time, x is the exit time, and p is the position of the group.

Control then passes to a step **380**.

Turning to the processing in the probe view, the input to the step **330** is the video stream from the second camera. In the step **330**, groups of people are formed in the probe view in a manner similar to that performed by the step **300** in the gallery view. The output of this step is a group identifier for each group of people, spatio-temporal attributes for the group such as positions, velocity, entry time, other attributes for the group such as number of people in the group, appearance attributes for the group such as appearance feature vectors using colour, gradients. Control then passes to a step **340**.

The step **340** decomposes the probe groups into probe contexts. If the number of probe groups is n, then there are 'n' probe contexts, each referred to as a local probe context. Each of the n local probe contexts has a different central node (being the source node for the local probe context in question) and (n−1) other nodes (being the destination nodes for the local probe context in question).

Each local probe context defines the relationships between the groups. The attributes that define the relationship are the relationship attribute. Each local probe context is defined in the same manner as that performed in the step **315**, however where the step **315** produces one predicted context for the tagged target group, the step **340** produces n contexts, one for each of the n probe groups that are present in the second camera FOV.

In one CBC implementation, a local probe context is represented by a star graph (see FIG. **11**) where the central (ie source) node is a probe group, and the other nodes are neighbouring nodes in the frame, or in a plurality of frames near the group which is defined as a central node.

Control then flows to step **350**. This step determines if there are more probe contexts to process. If this is the case, control follows a YES arrow and control flows to a step **360**. The step **360** gets the next probe context to process from the set of probe contexts which is the output of the step **340**. Control then flows to a step **370**, which is similar to the step **320**. The step **370** determines spatio-temporal dissimilarities for the n local probe contexts constructed in the step **340**.

Control then flows to a step **380** which performs inter-group dissimilarity matching between each of the n local probe contexts determined by the step **340**, and the predicted target group context determined by the step **320**. Each dissimilarity matching process produces a similarity score,

In one CBC implementation, the relationship attributes of the predicted tagged target context which are represented by the edges of the predicted context graph are matched against the relationship attributes of the local probe contexts which are represented by the edges of the local probe context graph by using the Hungarian algorithm, which provides optimal assignment (see http://en.wikipedia.org/wiki/Hungarian_algorithm the contents of which are incorporated herein by reference). The Hungarian algorithm provides the best partial match of the edges that match the local probe context in question with the predicted tagged target context. The output of this step **380** is a set of n similarity scores, each of which is the matching score of the local probe context in question with the predicted tagged target context.

In another CBC implementation, every relationship attribute of the predicted tagged target context is compared with every relationship attribute of the local probe context in question using a distance measure such as Euclidean distance. A linear combination of the distance scores of each

comparison is used as a similarity score and is used as a matching score of the local probe context in question with the predicted tagged target context.

Control then flows to a step **385** which stores n similarity matching scores obtained by matching local probe contexts with predicted tagged target context. In one CBC arrangement, the scores are stored in the **106** memory in a list. In another CBC arrangement the scores are stored in a database in the memory, as a field in a table.

Control then flows to the step **350** which determines if there are more local probe contexts to process. If there are more probe contexts, the process is repeated using the steps **360**, **370**, **380** and **385**. At the step **350**, if there are no more local probe contexts, control follows a NO arrow to a step **390**, where the process **304** ends.

The CBC arrangement can terminate at this point, on the basis of the inter-group processing by the process **304**. Alternately the CBC arrangement can also incorporate intra-group matching, described hereinafter in more detail with reference to FIGS. **4** and **5**.

Intra-Group Matching

FIG. **4** shows a flow diagram illustrating an intra-group matching process **400** performed by the processor **105** executing the CBC software application **133**. Inputs to the process **400** are the predicted images of the predicted gallery groups from the step **310**, the predicted attributes of the tagged target group from the step **310**, the images of the probe groups from the step **330**, and the spatio-temporal attributes of the probe groups output by the step **335** in the process **304**.

The input to a step **420** is the predicted attributes of the tagged target group from the step **310**, and the tagged target group image from the step **302** of the process **304**. The spatio-temporal features such as velocity, position, direction attributes of the predicted tagged target group obtained from the step **302**, when expressed as a vector, form the spatio-temporal attributes of the tagged target group.

Further in this step, appearance attributes are obtained from the predicted tagged target group image. The appearance attributes are used to generate an appearance model. The appearance model in one CBC implementation may be generated as a histogram of features where the features may be colour features such as R, G, B, H, S, V, Y, U, V, gradient features, local binary pattern features, texture features such as gabor. The features are extracted from the pixels of the tagged target group image.

In another CBC implementation, a self-similarity feature matrix is the appearance model as described in (eg see Kernalized contextual feature: Australian Patent No. AU 2012203828 the disclosure of which is incorporated herein by reference).

In another CBC implementation, an appearance model may be developed using symmetry driven accumulation of features (eg see http://profs.sci.univr.it/~cristanm/Publications_files/CVPR2010_Cristani.pdf the description referred to being incorporated herein by reference).

In another CBC implementation, Earth Mover's distance (eg see http://link.springer.com/article/10.1023/A:1026543900054#page-1 the description referred to being incorporated herein by reference) is used for appearance model. This model provides partial matching of appearances.

The spatio-temporal attributes and the appearance model from this step are input to a subsequent step **430**.

The input to a step **460** is the images of the probe groups from step **330**, and their spatio-temporal attributes output from the step **335** of the process **304**. The step **460** determines the attributes for each of the probe groups in a similar manner to that utilized in the step **420** for the tagged target group. The attributes are, in one CBC arrangement, stored in a hash table in the memory **106**, where the attributes are stored against each of the probe groups. Control then passes to a step **470**. This step initialises a variable L to a length (ie the number of groups) and the variable I is initialized to 1. Control then passes to a step **480**. This step retrieves the probe attributes for the probe group from the hash table where the attributes have been stored against the probe group identifiers. The attributes may be spatio-temporal attributes which may be a vector or a matrix of appearance attributes. Control then passes to the step **430**. This step performs intra-group similarity matching.

In one CBC arrangement, the appearance model of the tagged target group is matched against the appearance model of each probe group using Euclidean distance measurement between the two appearance models.

If the appearance model of the tagged target group is A_{tg} and if the appearance model of the probe group is A_p then the Euclidean distance between A_{tg} and A_p is determined to obtain an intra-group appearance similarity distance score. In another CBC implementation, Mahanobis or Bhattacharya distance is determined to obtain the intra-group appearance similarity score.

In another CBC arrangement, the spatio-temporal attributes of the tagged target group are subtracted from the spatio-temporal attributes of the probe groups to obtain a vector of intra-group spatio-temporal similarity scores.

In another CBC arrangement, the spatio-temporal and appearance attributes of the tagged target group are combined in a matrix. Similarly the spatio-temporal and appearance attributes of the probe groups are combined in a matrix. A Euclidean distance or other distance measure such as Mahanobis or Bhattacharya distance is then used to determine the similarity distance between the tagged target matrix and the probe matrix.

Control then passes to a step **440**. The input to this step is the (appearance and spatio-temporal or their combination) similarity intra-group matching distance scores that are stored in an array in memory or in a database table as a record. Control then passes to a step **490**. This step increments the variable counter 'i'. Control then passes to a step **495**. This step checks the counter 'i' against the number of probe groups 'L'. If 'i' is less than 'L' then control passes to the step **480** where the next local probe group attributes are retrieved from the hash table. If in the step **495**, 'i' is greater than 'L' then the process **400** ends.

FIG. **5** depicts a process **500** which combines the intra-group matching scores from the process **400** with the inter-group matching scores from the process **304**.

The input to a first step **580** is the intra-group similarity matching scores obtained from the step **440** in the process **400**. The intra-group similarity matching scores in one CBC implementation are the spatio-temporal similarity scores. In another CBC implementation the intra-group similarity matching scores are similarity appearance scores, and in yet another CBC implementation, the intra-group similarity matching scores are a combination of spatio-temporal and appearance similarity scores.

The inputs to a step **590** are the inter-group similarity matching scores obtained from the step **385** in the process **304**. The inter-group similarity scores are the similarity scores that are obtained by performing inter-group dissimilarity matching between the predicted context of the tagged target group and local probe contexts for each of the probe groups.

Control then passes to a step **530**. In this step the intra-group similarity scores are combined with the similarity scores of the inter-group matching. In one CBC implementation, the intra-group appearance similarity scores are multiplied with the inter-group similarity scores. In another CBC implementation, the intra-group appearance similarity scores are multiplied with the inter-group similarity scores.

In yet another CBC implementation, the intra-group appearance similarity and intra-group spatio-temporal similarity scores are added and then multiplied with the inter-group similarity scores. In another CBC implementation, the intra-group appearance, intra-group spatio-temporal and inter-group similarity scores are added.

In yet another CBC implementation, conditional weighted combining of scores is used. In this method, the intra-group appearance similarity scores and intra-group spatio-temporal similarity scores are used as a weight to the inter-group scores.

Let us consider a CBC arrangement in which the intra-group appearance similarity scores, intra-group spatio-temporal similarity scores and inter-group similarity scores are incorporated into an array. The step **530** retrieves the index of smallest score of the matching result, which indicates which group is similar to the tagged target group, from each of the arrays.

Let the three indices be as follows:

intra_group_appearance_index;

intra_group_spatio_temporal_index; and

inter_group_index.

In one CBC arrangement, if the intra_group_appearance_index is same as the inter_group_index then the intra-group appearance similarity score is used as a weight and it is multiplied with inter-group similarity score.

Alternately, if the intra_group_spatio_temporal_index is same as the inter_group_index, then the intra_group spatio_temporal similarity score is used as a weight and it is multiplied with inter-group similarity score.

However, if the intra_group_spatio_temporal_index and intra_group_appearance_index is not same as the inter_group_index matching result, then the intra-group similarity score is not combined with the inter-group similarity score.

The output of the step **530** is the combined scores of the intra-group similarity scores and inter-group similarity scores. Control then passes to a step **540**.

The step **540** is a matching step, which determines the different matching scores of the probe groups against the tagged target group. Matching is determined by the combined scores from the step **530**. The result with the smallest matching score is the group that matches the tagged target group.

In yet another CBC implementation, a ROC curve can be generated with the labels and scores of the matching groups. The ROC curve is used to generate a matching threshold. If the lowest matching score is above or equal to the threshold (e.g. **5**), then the best matched group obtained from the step **530** is considered to be the closest match to the tagged target group. Otherwise, it is not considered to be the closest match to the tagged target group.

Alternative Embodiment for Inter-Group Matching Process **304**:

In another CBC implementation of the process **304** (ie the inter-group matching process in FIG. **3**) the step **310** is omitted. In this case, the predicted context of the tagged target group in the second camera FOV from the step **315** is replaced by the context of the tagged target group in the gallery view (ie the first camera FOV). In one such CBC implementation the spatio-temporal attributes of the group such as velocity, exit time, number of people in the group are used as attributes in the context of the tagged target group. The output of this step is the vector-context of the tagged target group which is a vector of the relationship attributes between the groups of a star graph.

Alternative Embodiment for Inter-Group Matching Step **310**

In one case the predicted image of the predicted group **620***p* in the probe view is same as the gallery image of the gallery group **6201**. In another CBC system, the predicted image may be predicted based on factors such as lighting conditions of the probe view. If the lighting conditions in the probe view are different to that of the gallery view, then the colour values of the pixels of the gallery image may be modified. In one case, the modification may be learnt by comparing the R,G,B pixel values in the probe view and gallery view using machine learning algorithms such as SVM.

Alternative Embodiment for Inter-Group Matching Step **320**

In one CBC system, step **320** is omitted and the control passes to step **380** from step **315** in FIG. **3**.

In one case, all the attributes of the predicted groups in the predicted context, such as appearance, spatio-temporal attributes are used for inter-group dissimilarity matching. In this case, in the step **340** other attributes such as appearance attributes of the probe groups in the local probe context are used along with spatio-temporal attributes. Also in the step **370**, other dissimilarity attributes such as appearance along with spatio-temporal attributes of the probe contexts are passed to the step **380**.

In another case where the step **320** is omitted, only spatio-temporal attributes of the groups in the predicted context in the step **310** are used for inter-group dissimilarity matching. The control from the step **315** flows to the step **380**.

Illustration

FIGS. **6**, **7**, **8**, **9**, **10** and **11** provide an illustration of an embodiment of the CBC arrangement. In this illustration, we assume two PTZ cameras camera **1** and camera **2**, which are spaced 10 meters apart in the same straight line (ie the x coordinates of camera **1** and camera **2** are the same). The video stream from camera **1** is the first view or the gallery view, and the video stream from camera **2** is the second view or the probe view. For both cameras, the conversion matrices (homography matrices) of the 2-D image co-ordinates to the ground plane co-ordinates are determined from camera calibration. By using the conversion, the ground plane co-ordinates of each person's foot are obtained, thus giving their 'position'. Position is a 2-D position with x and y co-ordinates represented as (x, y). By tracking the position of a person through many frames, and with the knowledge of frames per second (FPS) which in the present example is 22 FPS, a velocity of the person can be determined. By tracking the position of a person across many frames, a direction of their travel is determined. By using velocity, direction and position, groups can be formed in both the gallery (FIG. **6**) and the probe (FIG. **7**) camera views. People with similar velocity, direction and positions are grouped together.

FIG. **6** is an example of a frame streamed from camera **1** at a time t**1** which is say 13:10:20. FIG. **7** is an example of a frame streamed from camera **2** at a time t**2** which is say 13:10:26. In FIG. **6**, there are four groups in the frame of a video stream of camera **1**, namely **6051**, **6101**, **6151** and **6201**. The group **6051** is selected by the user as the tagged target group by using a user interface such as the keyboard **102** or the mouse **103**. FIG. **7** is a frame of the video stream

of camera **2** at the time t**2**, which is the most probable time at which the groups from FIG. **6** enter the FOV of camera **2**. The probable time is the time at which it is predicted that the group can be seen in the other cameras FOV. It is determined when the group is about to exit the first camera's FOV, and is computed by considering the known distance between the cameras and the velocity of the groups by using the formula distance between the cameras/velocity of the group. In this case it is assumed that the groups move with uniform velocity. The groups depicted in FIG. **6** are shown in FIG. **7**. The Group **6051** in FIG. **6** is the group **6052** in FIG. **7**. The group **6101** in FIG. **6** is group **6102** in FIG. **7**. The group **6151** in FIG. **6** is the group **6152** in FIG. **7**. The group **6201** is the group **6202** in FIG. **7**. In this example, it is necessary to identify which of the groups in FIG. **7** is most probably the tagged target group **6051**.

Each group has three spatio-temporal attributes namely velocity, position and time which is exit time from the first camera FOV or entry time for the second camera FOV. A position (such as **6251**) of a group (such as **6051**) can, in one CBC arrangement, be defined as the ground plane co-ordinates of a midpoint of a lower edge of a bounding box for the group in question, where the bounding box is a 2-D rectangle (such as **6241**) around the group members as illustrated in FIG. **6**. A velocity of the group is obtained by using the ground plane co-ordinate positions for a group and tracking them over time.

Position is obtained at exit time from the FOV of the first camera. Exit time is the time when a group exits out of the field of view of the first camera and entry time is the time when the group enters the field of view of the second camera.

In the description below, a subscript below the spatio-temporal attribute indicates that the spatio-temporal attribute belongs to that group. For example V_{6051} is the velocity of the group **6051**.

For the gallery view, (velocity, position, exit time) spatio-temporal attributes of the different groups are as follows:
Group**6051**: (V_{6051}, $[X, Y]_{6051}$, T_{6051}),
Group**6101**: (V_{6101}, $[X, Y]_{6101}$, T_{6101})
Group**6151**: (V_{6151}, $[X, Y]_{6151}$, T_{6151})
Group**6201**: (V_{6201}, $[X, Y]_{6201}$, T_{6201})
Similarly the spatio-temporal attributes (velocity, position, entry time) for the groups in the probe view are as follows:
Group **6052**: (V_{6052}, $[X, Y]_{6052}$, T_{6052}),
Group**6102**: (V_{6102}, $[X, Y]_{6102}$, T_{6102}),
Group**6152**: (V_{6152}. $[X, Y]_{6152}$, T_{6152})
Group**6202**: (V_{6202}. $[X, Y]_{6202}$, T_{6202}).
Predict Spatio-Temporal Attributes
Obtain Predicted Context for Tagged Target Group

The gallery groups in FIG. **6** are **6201**, **6151**, **6051** and **6101**. The gallery group **6051** is the tagged target group. The step **310** predicts the spatio-temporal attributes for each of the gallery groups **6201**, **6151**, **6051** and **6101**. These predicted spatio-temporal attributes together with the corresponding images (predicted images) of the gallery groups, constitute the predicted groups **620***p*, **615***p*, **605***p* and **610***p*, in the second camera FOV, depicted in FIG. **8**, these predicted groups being associated with the corresponding gallery groups **6201**, **6151**, **6051** and **6101**. In this case the gallery images are assumed to be the predicted images in the probe view.

FIG. **9**(*p*) is a star graph representation depicting a predicted context for the tagged target group **6051** (having a corresponding predicted group **605***p*), the star graph having a source node **905***p*. The predicted group **605***p* associated with the tagged target group **6051** is represented by the centre G' (ie **905***p*) of the star graph in FIG. **9**(*p*).

The other neighbouring gallery groups **6201**, **6151**, and **6101** with their respective predicted groups **620***p*, **615***p*, and **610***p*, being represented by respective nodes **920***p* (ie B'), **915***p* (ie L'), and **910***p* (ie C') are the other groups depicted by the star graph.

The predicted context of the tagged target group, depicted by FIG. **9**(*p*), represents the relationship between the predicted attributes of the gallery groups where the attributes are in this case spatio-temporal attributes. This is determined by the step **315** in FIG. **3**.

The predicted spatio-temporal attributes of the gallery groups are obtained as follows. The predicted velocity is the velocity of the gallery group, the predicted x value of the position is the x value of the position of the gallery group, the predicted y value of the position is the y value of the gallery group plus 10 plus a portion of field of view distance, and the predicted entry time is the time the group will be seen in the probe view, which is obtained by the exit time with the likely time required to travel the distance between the cameras in this case 10 meters.

In this illustration, the predicted spatio-temporal attributes (predicted velocity, predicted position, predicted entry time) of the four groups represented as vectors are as follows:
Group**605***p*: (V'_{6051}, $[X',Y']_{6051}$, T'_{6051}),
Group**610***p*: (V'_{6101}, $[X',Y']_{6101}$, T'_{6101}),
Group**615***p*: (V'_{6151}, $[X',Y']_{6151}$, T'_{6151}),
Group**620***p*: (V'_{6201}, $[X',Y']_{6201}$, T'_{6201}).

Rg'i' (ie **911***p*) is the relationship between group **605***p*, which is node **905***p* and group **615***p* which is node **915***p* which is represented by the directed edge of the graph in FIG. **9**(*p*) and this relationship attribute is a vector obtained by taking the difference between the corresponding spatio-temporal group attributes. For example, Rg'i' is the relationship attribute which has the vector (V'_{6151}-V'_{6051}, $[X',Y']_{6151}$-$X',Y']_{6051}$, T'_{6151}-T'_{6051}) which is the difference between the predicted spatio-temporal attributes of the group **6151** and the group **6051**. Similarly other relationships are obtained for edges **912***p* and **913***p*. The output of the predicted context is the vector of relationship attributes.
Decompose into Local Probe Contexts

This involves, for each of the probe groups, obtaining a corresponding local probe context. FIG. **9** (*a*), FIG. **9**(*b*), FIG. **9**(*c*) and FIG. **9**(*d*) are the local probe contexts represented by star graphs for each of the probe groups shown in FIG. **7**. These are determined by the step **340** in FIG. **3**.

Thus for example FIG. **9** (*a*) is the local probe context represented as a star graph for the group **6202**.

The group **6202** has the group attributes (5.2_{6202}, $[0.9, 17.8]_{6202}$, $10{:}26_{6202}$), where 5.2 is the velocity with which the group walks, which is 5.2 kms/hour, [0.9, 17.8] is the [x,y] positions at the centre of the bounding box in FIG. [**7**] of **6202** and 10:26 is the entry time when the frame was visible in the field of view of camera **2**.

The group **6202** is represented by a node B (ie **920**), a node L (ie **915**) represents the group **6152** which has group attributes (5_{6152}. $[2.3,21.1]_{6152}$,$10{:}26_{6152}$), a node G (ie **905**) represents the group **6052** which has group attributes (5.0_{6052}, $[0.5, 21.6]_{6052}$, $10{:}25_{6052}$), a node C (ie **910**) represents the group **6102** which has group attributes (4_{6102}, $[-1.1,2.8]_{6102}$,$10{:}23_{6102}$).

Rbl is a relationship attribute represented by the directed edge **926** between the nodes B and L. The relationship attribute Rbl is a vector obtained by taking the difference between the spatio-temporal attributes of B and L, and thus Rbl is the vector (V_{6152}-V_{6202}, $[X,Y]_{6152}$-$[X,Y]_{6202}$, T_{6152}-

T_{6202}). Similarly Rbg is a relationship attribute represented by a directed edge **931** between the nodes B and G, and Rbc is a relationship attribute represented by a directed edge **936** between the nodes B and C. Similarly the local probe contexts for the group **6152** is represented by FIG. **9**(*b*), the local probe context for group the **6102** is represented by FIG. **9**(*c*), and the local probe context for the group **6052** is represented by FIG. **9**(*d*).

Compare the Probe Contexts with the Predicted Context Inter-Group Matching

Once the predicted context (see FIG. **9**(*p*)) and the local probe contexts (see FIGS. **9**(*a*)-**9**(*d*)) have been constructed, then for each of the probe contexts, a bi-partite graph having (i) the relationship attributes of the predicted context, and (ii) the relationship attributes of the local probe context is constructed. This enables the predicted context to be compared to the local probe context to produce a corresponding distance score. This is determined by the step **380** in FIG. **3**.

For example, in order to compare the predicted tagged target group context FIG. **9**(*p*) to the probe context FIG. **9**(*a*), a bipartite graph with the relationships of the predicted context and probe context is constructed as illustrated in FIG. **10**.

FIG. **10** depicts an example of a bipartite graph with relationships of the predicted tagged target context and the probe context in question as the nodes. Once the bipartite graph is constructed, a minimum cost assignment in the graph (where assigning one set of nodes to the others while the total assignment cost is minimised) is determined using the Hungarian algorithm.

An edge value which is the norm between the node vectors gets passed to the Hungarian algorithm. For example, Rg'i' is represented by a vector (4, [0.1 −7.3], 0) and Rbl is represented by a vector (0.2, [−1.4 −3.3], 0.3). The value of an edge **1003** is the Euclidean distance between the two vectors Rg'i' and Rbl.

Similarly edge values are computed for all the edges in the bipartite graph in FIG. **10** and these edge values are normalized and passed to the Hungarian algorithm to compute the minimum cost assignment, which is a distance score between the two graphs.

The distance is a real number like 2.34.

Similarly, the distance score between the predicted context FIG. **9**(*p*) and other local probe contexts FIG. **9**(*b*), FIG. **9**(*c*) and FIG. **9**(*d*) are computed. The distance scores are normalized and the one with the shortest distance (ie the best similarity score) provides the best match between the predicted context and the local probe context. Accordingly, the probe group whose local context is the closest to the predicted context is most similar to the tagged target group.

If, in the comparisons, it is found that FIG. **9**(*d*) is the closest match to FIG. **9**(*p*), this indicates that node G which is for group which is **6052** is most similar to node G' which the is the tagged target group **6051** with predicted attributes.

Intra-Group Matching

Further, the nodes B (ie **920**), L (ie **915**), C (ie **915**) and G (ie **905**) can be matched with G'(ie **905***p*) for intra-group matching. The spatio-temporal attributes of each of the nodes are matched with the spatio-temporal attributes by taking the Euclidean norm. For example considering (V'_{6051}, $[X',Y']_{6051}$,T'_{6051}), which are the spatio-temporal attributes of the predicted tagged target group G', and (V_{6201}, $[X,Y]_{6201}$,T_{6201}) which are the spatio-temporal attributes for the group B', a Euclidean norm gives the matching score based on the spatio-temporal attributes. Also, the score can be obtained by appearance matching, where the R, G, B colour histogram are extracted from the two images of the groups and then compared with the distance score. The intra-group similarity score in one CBC implementation can be obtained by adding the appearance score and the matching score based on spatio-temporal attributes.

The distance score between the probe contexts and the predicted context can be obtained in one CBC implementation by adding or combining the intra-group similarity score with the inter-group similarity score. The distance score is used to match the tagged target group to the probe groups. The one with the smallest score provides the match between the probe group and the gallery group.

INDUSTRIAL APPLICABILITY

The arrangements described are applicable to the computer and data processing industries and particularly for the video surveillance industry.

The foregoing describes only some embodiments of the present invention, and modifications and/or changes can be made thereto without departing from the scope and spirit of the invention, the embodiments being illustrative and not restrictive.

The invention claimed is:

1. A method of matching a tagged target group, selected from a plurality of gallery groups in a first camera field of view, with probe groups in a second camera field of view, the method comprising:

determining a group context for the tagged target group;

determining, in the second camera field of view, probe contexts for the respective probe groups in the second camera field of view;

matching, using one or more processors, the group context against the probe contexts to produce respective similarity scores;

identifying, based upon the similarity scores, the probe group that matches the tagged target group;

determining appearance models for the tagged target group and the probe groups;

matching the appearance model of the tagged target group against the appearance models of the probe groups to produce respective intra-group similarity distance scores; and

identifying, based upon the intra-group similarity scores, the probe group that matches the tagged target group.

2. The method according to claim **1**, wherein determining the group context further includes determining, in the second camera field of view, a predicted group context for the tagged target group.

3. The method according to claim **1**, wherein the group context and the probe context are dissimilarity contexts.

4. The method according to claim **1**, wherein the appearance model for the tagged target group is determined based upon the tagged target group in the first camera field of view.

5. The method according to claim **1**, wherein at least one of the predicted group context and the probe context are determined based upon filter criteria.

6. An apparatus for matching a tagged target group, selected from a plurality of gallery groups in a first camera field of view, with probe groups in a second camera field of view, the apparatus comprising:

one or more processors; and

memory storing instructions that, when executed by the one or more processors, cause the one or more processors to function as:

a first determining unit configured to determine a group context for the tagged target group,

a second determining unit configured to determine, in the second camera field of view, probe contexts for the respective probe groups in the second camera field of view,

a first matching unit configured to match the group context against the probe contexts to produce respective similarity scores,

a first identifying unit configured to identify, based upon the similarity scores, the probe group that matches the tagged target group,

a third determining unit configured to determine appearance models for the tagged target group and the probe groups,

a second matching unit configured to match the appearance model of the tagged target group against the appearance models of the probe groups to produce respective intra-group similarity distance scores, and

a second identifying unit configured to identify, based upon the intra-group similarity scores, the probe group that matches the tagged target group.

7. The apparatus according to claim **6**, wherein the first determining unit further is configured to determine, in the second camera field of view, a predicted group context for the tagged target group.

8. The apparatus according to claim **6**, wherein the group context and the probe context are dissimilarity contexts.

9. The apparatus according to claim **6**, wherein the appearance model for the tagged target group is determined based upon the tagged target group in the first camera field of view.

10. The apparatus according to claim **6**, wherein at least one of the predicted group context and the probe context are determined based upon filter criteria.

11. A non-transitory computer readable storage medium storing a computer executable program to perform a method of matching a tagged target group, selected from a plurality of gallery groups in a first camera field of view, with probe groups in a second camera field of view, the method comprising:

determining a group context for the tagged target group;

determining, in the second camera field of view, probe contexts for the respective probe groups in the second camera field of view;

matching, using one or more processors, the group context against the probe contexts to produce respective similarity scores;

identifying, based upon the similarity scores, the probe group that matches the tagged target group;

determining appearance models for the tagged target group and the probe groups;

matching the appearance model of the tagged target group against the appearance models of the probe groups to produce respective intra-group similarity distance scores; and

identifying, based upon the intra-group similarity scores, the probe group that matches the tagged target group.

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