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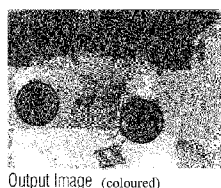
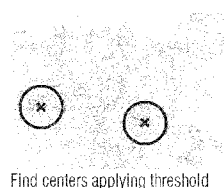
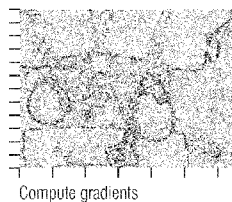
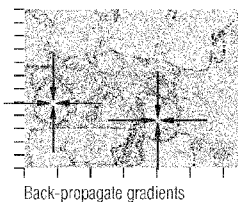
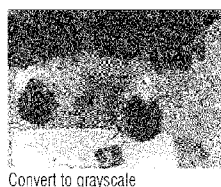
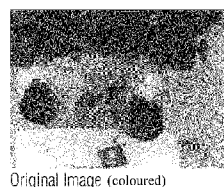
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(54) Title: VISION BASED OCCUPANCY DETECTION SYSTEM AND METHOD

FIG 3



(57) Abstract: The present invention relates to a occupancy detection system and method for use in lighting/HVAC control. The system uses the vision based algorithm to detect human head-top circles in top view videos captured by ceiling mounted camera. The color images converted to grayscale images and gradient filter are applied to find gradient vectors at each point of the image. The gradient vector then propagated backwards to find the center candidate. The center point accumulation and homogeneity constraint are used in combination with gradient back propagation to find the unique center candidate for near circular objects like human head.

Description

VISION BASED OCCUPANCY DETECTION SYSTEM AND METHOD

5 FIELD OF INVENTION

The present invention relates to a system and method of vision based occupancy detection using head-top circles. The inventive method has an occupancy detection algorithm for indoor lighting control that detects humans in videos captured through a ceiling mounted camera utilizing a head-top circle detection-based approach. The method is scale and illumination invariant and works well even for top-view videos captured through a fish-eye lens-camera system. The human head is visible consistently from a ceiling mounted camera, and due to near spherical shape of human head, the projection of head in 2-D plain (e.g. the camera plane) is always near circular (disc) in shape. The present method utilizes this characteristic of the human head top to accomplish occupancy detection in a circle detection-based framework.

20

BACKGROUND ART

Various approaches for human detection techniques have been discussed in various literatures, ranging from non vision based detection techniques such as PIR motion sensors, acoustic sensors, laser sensors to vision based detection techniques such as camera based techniques.

As is known in the art, PIR motion sensors have been used to detect different human motion events. Heat signatures are captured for each of these events. A PIR motion sensor with ultra low power consumption has been known in the art. A motion sensing device has been designed to switch off lights when there is no motion. The hardware design has been opti-

mized to conserve power. A fusion of wireless nodes with PIR sensors has been proposed to track human motion. The computational and memory requirements are minimized in order to make the system amenable to running on resource constrained devices such as wireless nodes. The main drawback of PIR based sensing technology is that it cannot be used for counting the number of people in the scene. Another major drawback is that pose and fall detection of subjects is very tricky with simple PIR motion sensors. Also in case of very little or no motion PIR motion sensors fail to detect human occupancy.

The acoustic systems designed for detection of acoustic events for describing human and social activity in meeting rooms. A fusion of audiovisual features has been proposed to improve the accuracy of acoustic event detection system. A human identification technique using acoustic micro-doppler signatures and band-pass sampling technique and gaussian mixture model-based human identification technique was also presented by Z. Zhang and A. G. Andreou ("Human Identification Experiments Using Acoustic Micro-Doppler Signatures", The Argentine Conference on Micro-Nanoelectronics, Technology and Applications, Buenos Aires, Argentina, Sept, 2008.). The accuracy of acoustics based human detection systems was not satisfactory enough for commercial deployment. It is also very difficult to analyze the pose/fall of a person and their unusual activities with acoustic system.

A method to detect human head-tops in videos is known using Kalman filter and mean-shift tracking. (H. Lu, R. Zhang and YW. Chen, "Head Detection and Tracking by Mean-shift and Kalman Filter", International Conference on Innovative Computing Information and Control (ICICIC 2008), pp. 357.) The technique employs the image color intensity information and the Local

Binary Pattern (LBP) to construct a fourdimensional histogram representative of the color intensity values and the texture of the target under study. The new object location is then determined by Mean Shift iteration after the predict location
5 is confirmed by Kalman filter. Color, texture, and motion features are integrated to track objects.

Another method for counting the people at crowded places using head-top detection using circle detection for top-view
10 videos is presented in REMOTE HEAD COUNTING AND TRACKING IN CROWDED SCENE VIA WWW/INTERNET (Hsin Chia Fu, Jian-Rong Chen, Hsiao T. Pao Department of computer science, National Chiao-Tung University Hsinchu, Taiwan, 300 ROC). Over-head images of crowded scene are collected from a set of head-down video
15 cameras. Each collected over-head image is then analyzed by head-counting and tracking software for estimating the number of heads in the scene. If the number of heads exceeds a pre-determined threshold, alarm signals and images of crowded scene are sent via Internet to the remote experts, so that
20 the on-site situation can be examined and discussed to see if any further action may be needed.

In another literature a method based on a Bayesian fusion approach using laser range data and camera images is presented
25 by Luciano Spinello and Roland Siegwart ("Human Detection Using Multimodal and Multidimensional Features", IEEE International Conference on Robotics and Automation, ICRA, pp. 3264-3269, May 2008.).

30 In addition many Patent literatures contains various methods for occupancy detection and dimensioning objects. Mechanical rulers are available in many stores, and they require contact

to the surface that they measure. Optical methods are available for measuring various properties of a scene.

Various patents describe using optical triangulation to measure the distance of objects from a video sensor. For example, in U.S. Pat. No. US5,255,064, multiple images from a video camera are used to apply triangulation to determine the distance of a moving target.

10 In a PCT publication, WO2011151232, an optical system for occupancy sensing, and corresponding method is disclosed. The system includes a plurality of optical line sensors, each consisting of a linear array of light sensing elements; and an optical light integrating device that integrates light
15 from rays with incidence angles subject to geometric constraints to be sensed by a light sensing element.

In an US publication, US2011267186, an optical method and system is disclosed. Therein successive images from an infrared camera are analyzed to detect thermal characteristics of an occupant as well as movement.

20 In a PCT publication, WO2011091868, a system and method for 2D occupancy sensing is disclosed. The 2D occupancy system for determining a position of a user (e.g. a human, an object or an animal) in an environment according to embodiments of the invention includes a host device and a plurality of motion detection devices wherein the host device and the plurality of motion detection devices are connected through a network. Each motion detection device has a viewing angle and
25 the viewing angle of any motion detection device overlaps with the viewing angle of at least one other motion detection device.
30

In another US publication US2004066500, occupancy detection and measurement, and obstacle detection using imaging technology is disclosed. Embodiments include determining occupancy, or the presence of an object or person in a scene or space. If there is occupancy, the amount of occupancy is measured.

Most vision based algorithms rely on additional information for human detection such as motion cues or manually marked triggers/trip wires. In addition, most of these techniques use side view cameras for human detection in which many rich features of the human body such as the skin/face color (hue), shape and movement of the limbs etc. are available.

There is a need for cost effective and energy efficient method for human detection for various purposes especially for use in automation of lighting and HVAC control to save energy. Our technique aims to perform human detection in top-view videos using ceiling mounted cameras.

Ceiling mounted cameras offer a cheap alternative in terms of cost as well as computation complexity as it can be readily integrated to existing ceiling fixtures (e.g., luminaires, smoke detectors, air-conditioner vents, etc).

The present method is fully automatic in the sense it does not require any additional manual inputs such as trip-wires or manual triggers for detection.

SUMMARY OF INVENTION

Energy efficiency of systems employing occupancy detection techniques depends on the accuracy of the human detection algorithm. Design of such accurate algorithms is a non-trivial problem with vision based detection techniques and particu-

larly challenging using ceiling mounted camera where only head-top is visible consistently. Herein disclosed is a novel vision-based occupancy detection algorithm using ceiling mounted cameras which utilizes the circularity of head shape for accurate detection. Experiments are conducted using an exhaustive video database and for varying illumination and ambience and showed that the said algorithm achieves a detection accuracy of up to 90%.

In the present disclosure novel occupancy detection algorithm is introduced using ceiling mounted cameras. In such a system, human detection implies detection of human head-tops since the only recognizable feature of human body available in all views is the head-top. Due to near-spherical shape of a human head, the projection of a head on a 2-D plane is always near-circular in shape. This characteristic of the human head-top is used to accomplish occupancy detection in a circle detectionbased framework.

Described herein is a system for occupancy detection techniques exploiting the centre point's distribution for head-top circles in a region. The system includes at least one ceiling mounted camera having fish-eye lens, a controller for executing an algorithm using ceiling mounted cameras that generates occupancy detection associated with the detection of human head tops predicted movement of occupants within each of the plurality of segments. The algorithm is a vision-based occupancy detection algorithm using gradient back propagation approach through ceiling mounted cameras which utilizes the circularity of head shape for accurate detection. The system further includes an output operably connected to the controller to communicate the occupancy estimates generated by the algorithm.

In an exemplary embodiment of the present invention vision-based occupancy detection algorithm using gradient back propagation approach in conjunction with Centre Points Accumulation technique for detection of imperfect circles with specific application to head-top detection.

In another exemplary embodiment of the present invention vision-based occupancy detection algorithm using gradient back propagation approach in conjunction with homogeneity criterion for detection of imperfect homogenous circles with specific application to head-top detection.

In another aspect, described herein is a method of detecting occupancy in a region exploiting the centre points distribution for head-top circles in a region. The method includes modelling using occupancy detection algorithm using ceiling mounted cameras. Due to near-spherical shape of a human head, the projection of a head on a 2-D plane (e.g. the camera plane) is always near-circular in shape. The characteristic of the human head-top is used to accomplish occupancy detection in a circle detection-based framework. The method further includes calculating modelbased predictions of occupancy within the region by detecting human head-tops by locating circles in grayscale images. The circles are detected by back propagating the gradients in the image and applying thresholds on accumulated points thereby detecting circle centres. The points are accumulated in a 3-D accumulator array of size $(p1, q1, r3)$, where $p1$ & $q1$ are the width and the height of the image respectively and $r3$ is the number of radius values. The value of $r3$ depends upon the range of radius values used for circle detection.

In another aspect, described herein is a system for detecting occupancy in a region using centre points distribution for head-top circles in a region. The system includes means for detecting each of the plurality of head top circles in a particular region. The system further includes means for calculating model-based detections of occupancy within the region based on state equations that model occupancy of each region, detecting human head-tops by locating circles in grayscale images, further the circles are detected by back-propagating the gradients in the image and applying thresholds on accumulated points thereby detecting circle centres. The points of the potential centre candidates are accumulated in a 3-D accumulator. After accumulation, a suitable threshold is applied to each 2-D (x,y) plane in accumulator array to detect circles of corresponding radii.

In another aspect, described herein is a computer readable storage medium encoded with a machine-readable computer program code for generating occupancy detection for a region, the computer readable storage medium including instructions for causing a controller to implement the said method. The computer program includes instructions for calculating model-based detections of occupancy within the region based on state equations that model occupancy of the region, detecting human head-tops by locating circles in grayscale images, further the circles are detected by back-propagating the gradients in the image and applying thresholds on accumulated points thereby detecting circle centres. The points of the potential centre candidates are accumulated in a 3-D accumulator. After accumulation, a suitable threshold is applied to each 2-D (x,y) plane in accumulator array to detect circles of corresponding radii.

As it is insufficient to model the head-top as a unique circle due to variability of the human head in terms of its shape and size among different people, hence, the parametric definition of a circle is used in terms of centre coordinates and radius (x, y, r) to model the head-top circle as an imperfect circle with x, y and r as random variables. Circle centre coordinates obtained by gradient back propagation algorithm form points in the (x, y, r) space. The circle centre points are accumulated in 3-D space to obtain the actual head-top circles. Further, the human head-tops appear as homogenous objects in top-view videos. The said property is used to distinguish head-top circles from random circles formed due to clutter in the scene.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

Embodiments of the invention are illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings wherein -

Fig 1 illustrates an overview of the disclosed system. The Controller (1) connected to a ceiling mounted video camera (2) having fish-eye lens system. The Controller also controls the switches for lighting/HVAC according to occupancy detection.

Fig 2 illustrates gradient back propagation for circular objects

Fig 3 illustrates circle detection using gradient back propagation

Fig 4 illustrates distribution of centre candidates for different values of radius

Fig 5 illustrates a 3-D volume for concentrating centre candidates along (x, y, r) dimensions;

Fig 6 illustrates homogeneity criterion gradient sums using circular integrator filters;

DETAILED DESCRIPTION

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Advances in the fields of computer vision & image processing have led to generation of significant research interest in the area of vision based occupancy detection. Human occupancy detection is an integral component for various control applications e.g. automatic lighting control, HVAC control etc.
10 Most of the lighting control systems rely on occupancy detection techniques to control lighting in a specified region.

Further energy-efficient lighting system design has for long
15 been an active research area. Recently significant research interest has also been generated in the area of lighting control systems for outdoor as well as indoor lighting equipment's. Most of the lighting control systems rely on occupancy detection techniques to control lighting in a specified
20 region. Herein disclosed is a novel occupancy detection algorithm for indoor lighting control that detects humans in videos captured through a ceiling mounted camera utilizing a head-top detection-based approach.

25 The disclosed method is scale and illumination invariant and works well even for top-view videos captured through a fish-eye lens-camera system. The method gives a detection accuracy of 90% (Lower of the two: Recall rate- 90% & Precision rate- 95%). Experiments have been carried out for top-view videos
30 of 15 people taken at two different locations, with varying illumination, ceiling height and ambience. The head-top detection in top-view videos is performed utilizing a novel circle detection-based approach. The work specifically fo-

cuses on a novel extension to the head-top detection algorithm which improves the accuracy of the overall system by about 7%.

The term 'region' is used throughout the description to refer to both a region as well as various sub-divisions of the region. For instance, in the exemplary embodiment shown in figures, the term 'region' refers to both the area in general as well as to the individual sub-regions or zones e.g. rooms.

Therefore, generating occupancy detection for the region would include generating occupancy estimates for each of the individual zones.

In addition, the term 'occupancy detection' is used throughout the description and refers generally to output related to occupancy. Therefore, an occupancy detection for a region may include data such as a number of occupants within the region, a probability associated with all possible occupancy levels associated with the region changes in occupancy, detecting something (human); catching sight of human, data indicative of the reliability of confidence associated with occupancy (e.g., covariance), as well as other similarly useful data related to occupancy.

The application discloses a system and method for detecting occupancy based on exploiting the centre point's distribution for head-top circles. In an exemplary embodiment, occupancy is detected based solely on Gradient Back Propagation Approach. This application expands upon the scope of the prior art, disclosing additional embodiments and methods of implementing occupant detection.

Occupancy detection has traditionally been accomplished using either vision-based (e.g., using mast/ceiling mounted cameras or non vision-based techniques such as PIR, Ultrasonic, acoustic, etc. Vision-based occupancy detectors have been

known to be cost effective and power efficient for both indoor/outdoor scenarios, where a camera is mounted on a mast with a clear view of entry/exit points or locations with movement of people. For indoor scenarios, these sensors can be used to not only detect human occupation but they can also be useful for people counting, detection of unusual activity or possible fall of a person (e.g., in assisted living scenarios).

The disclosed novel occupancy detection algorithm using ceiling mounted cameras in a system as shown in fig. 1. In such a system, human detection implies detection of human head-tops since the only recognizable feature of human body available in all views is the head-top. Due to near-spherical shape of a human head, the projection of a head on a 2-D plane (e.g. the camera plane) is always near-circular in shape. The characteristic of the human head-top to accomplish occupancy detection in a circle detection based framework is exploited. To this end, a comparative analysis of two techniques is presented for circle detection in images namely, Hough circles and gradient back propagation. On analysis, it may be seen that the gradient back propagation algorithm yields 40% reduction in error-rate compared to Hough circlesbased approach for human detection problem.

In top-view videos there are no rich features available for human detection. The conventional features like the skin color (hue), the face of the person, the shape and the movement of the limbs, etc. cannot be used in this view. A lot of human detection techniques rely on facial features and limb shape/movements for detecting human presence. In the top-view, head-top is the only feature that is visible consistently in all poses for human detection. Hence the problem of

human detection boils down to human head-top detection in top-view. A human head resembles solid sphere in shape and the projection of a sphere is always circular at all angles. Head-top detection thus implies finding circles (disks) in top-view videos. We present an analysis of the Gradient back-propagation based approach for circle detection in the context of person detection.

In the discussion above, a circle detection algorithm for grayscale images utilizing the gradient direction alongwith the gradient magnitude is disclosed. The algorithm also presents a fixed computational complexity for a given image resolution.

The Fig. 2 illustrates the gradient back propagation for circular objects. The disclosed algorithmic approach detects human head-tops by locating circles in grayscale images. The circles are detected by back-propagating the gradients in the image and applying thresholds on accumulated points thereby detecting circle centers. The points are accumulated in a 3-D accumulator array of size $(p1, q1, r3)$, where $p1$ & $q1$ are the width and the height of the image respectively and $r3$ is the number of radius values. The value of $r3$ depends upon the range of radius values used for circle detection. After accumulation, a suitable threshold can be applied to each 2-D (x, y) plane in accumulator array to detect circles of corresponding radii. However, in order to apply the said approach for detection of head-top circles, which are imperfect circles, further improvements need to be done to the algorithm.

For head-top circles, the gradient back-propagation approach does not yield a unique center candidate. Instead, it returns a region around the actual circle center with all the points

in the region satisfying the circle detection threshold. For perfect (near-perfect) circles, one can get clear local maxima in the accumulator array at the centre of the circle.

Hence the other centre candidates can be suppressed in the

5 region by finding local maxima around the centre in the accumulator array. However, for imperfect circles (e.g. head-top circles), the region around the centre in the accumulator array typically consists of a distribution of points with high accumulation values. Hence, a simple approach to find local

10 maxima may not fetch the exact centre coordinates. Similar distribution is observed for different values of radius close to the actual radius value. This distribution of accumulation values along the image axes (x,y) for different radii values for the original image in fig.1 has been depicted in fig.4.

15 Fig. 4 illustrates the distribution of centre candidates for different values of radius. It is clear from fig. 5 that for imperfect circles, candidate center points are distributed in a 3-dimensional space constituting the 2 image axes (x,y) and a third radial axis. For a 2-dimensional distribution of circle points, one can concentrate the centre candidates using a mexican hat-shaped 2-D filter. This essentially finds the centroid of the distribution of the center candidates in the 2-D accumulator space. A threshold can be applied to the filtered accumulator array to find the actual center points. We

25 can apply the same principle in 3-D space $(x,y,radius)$ to find centroid of the distribution of the center candidates. In order to apply centroiding on center candidates in 3-D space one can use a 3-D filter as shown in fig 5 which illustrates a 3-D volume for concentrating centre candidates along $(x,y,radius)$ dimensions.

As shown in fig. 5, an ellipsoid has been selected as the 3-D volume for integrating center candidates in the accumulator array, which is consistent with the choice of a circular filter along the 2-D image axes (x, y) . The span of the volume is longer along the radial axis as found through experiments that the distribution of center candidates is spread across a longer range on the radial axis compared to the image axes. The ellipsoid shaped 3-D filter is applied to accumulate the potential center candidates in the 3-D (x, y, r) accumulator array. The accumulation values at all points within the said ellipsoid in the neighborhood of a point in the accumulator array are integrated. A threshold is then applied to the integrated value at each pixel location to find actual circle centers. This technique yields about 7% improvement in the detection accuracy for head-top circles.

In the gradient back propagation approach the direction of the gradient vector is used, along with its magnitude, in circle detection framework. First the original RGB image is converted to grayscale and then filters are applied to find gradient vector at each point on the grayscale image. The gradient vector can be represented as (gr, θ) in the polar coordinate system, wherein gr is the magnitude of the gradient and θ is the direction. For a dark colored circular object in the image, the gradient vectors at the object boundary appear to emerge out of the object along radial lines as shown in fig. 2.

For such an object, if the gradient vectors are propagated backwards using a fixed distance, they all converge at the centre of the object if the distance value selected is equal to the radius of the circle. This is depicted in fig. 2(b). This is the main concept behind circle detection using gradi-

ent back propagation, the algorithm for which is explained below:

- 1) Convert the original RGB image to grayscale and apply two-dimensional gradient filters (sobel, canny etc.) to find gradient vectors (r, θ) at each point on the image.
- 2) Choose a range of radius values $(r1, r2)$ to detect circles with radii lying in this range in the image. Here $r1$ & $r2$ are integer values representing the minimum and maximum radius values respectively in terms of number of pixels. Hence the possible radius values for the chosen range are integers between $(r1, r2)$. Let $r3$ be the no. of radius values.
- 3) Initialize a 3-D accumulator array (accm), of size $(p1, q1, r3)$ with zeros, where p and q are the width and the height of the grayscale image respectively.
- 4) For each value of radius (rv) in the chosen range $(r1, r2)$, create a vector $(rv, \theta + \pi)$. This vector represents propagation of the gradient with distance rv in the reverse direction $(\theta + \pi)$ i.e back-propagation of the gradient. Find this backpropagation vector (BPV) of the gradients for all points in the image.
- 5) Find projections of the BPV along the image axes i.e. (x, y) coordinates and round them to integral pixel values. These can be calculated as:
$$x1 = [rv * \cos(\theta + \pi)]; y1 = [rv * \sin(\theta + \pi)]$$
- 6) Add this BPV vector to the corresponding pixel location i.e. the point for which the BPV vector was calculated. If $(p1, q1)$ is the current pixel location, the resultant location can be found as:

$p2 = p1+x1; q2 = q1+y1$

7) Add the value of gradient magnitude at pixel location
(p1,q1) in the grayscale image to the existing value at loca-
5 tion (p2,q2,rv) in the accumulator array (accm). Repeat the
above steps for all pixels in the grayscale image and for all
radius values (r3).

8) The accumulator array gets populated with the gradient
10 values of the original grayscale image. A suitable threshold
can then be applied to each 2-D (x,y) plane in accumulator
array to detect corresponding circles of radii between (r1,
r2). The entire process is depicted in fig. 3. The choice of
threshold depends on the circularity of the object to be de-
15 tected. For near perfect circles in the image, a high value
of threshold is preferable, whereas, if the circles in the
original image are imperfect or incomplete, it is better to
choose a low value for this threshold.

20 The head-top circles, as can be observed in the original im-
age fig. 2, are homogenous in nature i.e. the pixels in the
head-top part of the image have similar intensity or gray-
scale values. The property of head-top circles is used to im-
prove the detection performance of our algorithm by applying
25 a homogeneity constraint on the detected circles. This helps
in eliminating false positive detection of circles formed
with boundaries of heterogeneous objects or due to excessive
clutter. There are a lot of different criteria to check the
homogeneity of an object in an image, some of the simple ones
30 being -variance/standard deviation of pixel values within the
object, number of edge points within the object in the edge-
map of the image, sum of gradient values within the object
etc. Any one of these methods can be used depending upon the

type of homogeneity to be checked. The sum of gradients as the homogeneity criteria is chosen as the gradients on the grayscale image for earlier steps has been already computed.

After detecting circles in the image, gradients are inte-

5 graded for all the points within the detected circles in the grayscale image. A suitable threshold is then applied to the

gradient sums to find head- top circles among all the de-

tected circles. The gradient sums can also be calculated up-
front by applying circular 2-D filters on calculated gradient

10 array for the grayscale image. This approach yields gradient

sums for all the points in the image. The gradient sum values

can be found at detected circle centres and apply threshold
only on those selected values.

15 It can be observed from fig.6 that homogenous regions of the grayscale image have lower values of gradient sums (dark re-

gions in the filtered image) compared to heterogene-

ous/cluttered regions. This has been used to distinguish ho-

20 mogenous head-top circles from false positive detections of

heterogeneous circles. This is accomplished by selecting only
those circles from all detected circle candidates which have

a gradient sum value less than a predefined threshold. The
value of the threshold for homogeneity depends on the circu-

25 larity of the object to be detected. For perfect (in shape)
and homogenous circles (disks), it is preferable to set a low
value for the homogeneity threshold. For head-top circles,

30 which are imperfect (but homogenous) circles, a higher value
should be set as threshold.

Therefore, as discussed above a novel head-top detection al-
gorithm is disclosed utilizing gradient back-propagation in
grayscale images for use in conjunction with ceiling mounted
camera(s) [at least one camera or a plurality of camera(s)]

operably connected] for occupancy detection applications. The algorithm performs person detection in top-view videos captured through ceiling mounted cameras having fisheye lens-camera system. Further the Centre Points Accumulation technique is used for detection of imperfect circles has been proposed with specific application to head-top detection. This has been suggested as an extension to the said head-top detection algorithm utilizing gradient back-propagation. In addition, a homogeneity criterion for detection of imperfect homogenous circles is also disclosed with specific application to head-top detection. This has been suggested as an extension to our head-top detection algorithm utilizing gradient back-propagation. The proposed technique detects head-tops in grayscale images for use in conjunction with ceiling mounted cameras for occupancy detection applications. In another exemplary embodiment, the said algorithm and the proposed techniques are used in conjunction for improving the output result. The algorithm performs person detection in top-view videos captured through ceiling mounted cameras having fisheye lens-camera system. This view has certain advantages like occlusions are minimum and the coverage is good i.e. the number of cameras needed to monitor a certain area is least in this view.

For the purposes of testing and records, a database of top-view videos has been generated by installing a ceiling mounted camera in a discussion room and a lab inside our office premises. The database captures variability in poses, head-shapes, ceiling height, and illumination conditions. The developed algorithm has been tested using the generated database and a detection accuracy of 90% has been achieved. This method outperforms the Hough circles-based approach for circle detection as it utilizes more useful information about

circular shapes as compared to the Hough-circles-based approach.

Although the foregoing description of the present invention
5 has been shown and described with reference to particular embodiments and applications thereof, it has been presented for purposes of illustration and description and is not intended to be exhaustive or to limit the invention to the particular
10 embodiments and applications disclosed. It will be apparent to those having ordinary skill in the art that a number of changes, modifications, variations, or alterations to the invention as described herein may be made, none of which depart from the spirit or scope of the present invention. The particular
15 embodiments and applications were chosen and described to provide the best illustration of the principles of the invention and its practical application to thereby enable one of ordinary skill in the art to utilize the invention in various
20 embodiments and with various modifications as are suited to the particular use contemplated. All such changes, modifications, variations, and alterations should therefore be seen as being within the scope of the present invention as determined by the appended claims when interpreted in accordance with the breadth to which they are fairly, legally, and equitably entitled.

Claims

1. A system for occupancy detection exploiting the centre point's distribution for head top circles in a region,
5 the system comprising:
at least one ceiling mounted camera having fish-eye lens operably connected to a controller configured for executing an algorithm that generates occupancy detection associated with the detection of human head tops and
10 predicted movement of occupants within each of the plurality of regions, wherein the algorithm is a vision-based occupancy detection algorithm for detection of head-top circles utilizing gradient back propagation approach in conjunction with center point accumulation
15 and/or homogeneity constraint; such that
an output operably connected to the said controller communicates the occupancy detection generated by the said algorithm.
- 20 2. A system for occupancy detection as claimed in claim 1, wherein the nearspherical shape of a human head top is used to accomplish occupancy detection in a circle detection-based framework.
- 25 3. A system for occupancy detection as claimed in claim 1, wherein the image captured by the ceiling camera is converted to grayscale and then gradient filters are applied to find gradient vector at each point on the grayscale image.
- 30 4. A system for occupancy detection as claimed in claim 1, wherein the gradient back propagation approach includes

the direction of the gradient vector, along with its magnitude, in circle detection framework.

5. A system for occupancy detection as claimed in claim 3,
5 wherein the gradient vector is represented as (gr, θ) in the polar coordinate system, wherein gr is the magnitude of the gradient and θ is the direction.

6. A system for occupancy detection as claimed in claim 3,
10 wherein for an circular object, the gradient vectors emerging out of the object along radial lines are propagated backwards using a fixed distance, they all converge at the centre of the object when the distance value selected is equal to the radius of the
15 circle.

7. A system for occupancy detection as claimed in claim 1,
wherein visionbased occupancy detection algorithm using gradient back propagation approach comprising the steps
20 of :
converting the original RGB image to grayscale and apply two-dimensional gradient filters to find gradient vectors (r, θ) at each point on the image;
selecting a range of radius values $(r1, r2)$ to detect
25 circles with radii lying in this range in the image,
where $r1$ & $r2$ are integer values representing the minimum and maximum radius values respectively in terms of number of pixels;
initializing a 3-D accumulator array $(accm)$, of size
30 $(p1, q1, r3)$ with zeros, where p and q are the width and the height of the grayscale image respectively;
creating a vector $(rv, \theta + \pi)$ for each value of radius (rv) in the selected range $(r1, r2)$, where the said vec-

tor represents propagation of the gradient with distance
rv in the reverse direction ($\theta + \pi$) i.e back-propagation
of the gradient;

finding back-propagation vector (BPV) of the gradients
for all points in the image and the projections of the
BPV along the image axes i.e. (x,y) coordinates and
round them to integral pixel values;

adding the said BPV vector to the corresponding pixel
location; adding the value of gradient magnitude at
pixel location (p1,q1) in the grayscale image to the ex-
isting value at location (p2,q2,rv) in the accumulator
array (acmm);

and

repeating the above steps for all pixels in the gray-
scale image and for all radius values (r3).

8. A system for occupancy detection as claimed in claim 7,
wherein the accumulator array (acmm) gets populated with
the gradient values of the original grayscale image.

9. A system for occupancy detection as claimed in claim 7,
wherein the
projections of the BPV along the image are calculated
as:

$$x1 = [rv * \cos(\theta + \pi)]; \quad y1 = [rv * \sin(\theta + \pi)]$$

10. A system for occupancy detection as claimed in claim 7,
wherein a suitable threshold is applied to each 2-D (x,
y) plane in accumulator array to detect corresponding
circles of radii between (r1, r2) and the choice of
threshold depends on the circularity of the object to be
detected.

11. A system for occupancy detection as claimed in claim 10,
wherein for near perfect circles in the image, a high
value of threshold is preferable, whereas, if the cir-
cles in the original image are imperfect or incomplete,
5 a low value for threshold is selected.
12. A system for occupancy detection as claimed in claim 1,
wherein the visionbased occupancy detection algorithm
using gradient back propagation approach is used in con-
10 junction with Centre Points Accumulation technique for
detection of imperfect circles with specific application
to head-top detection.
13. A system for occupancy detection as claimed in claim 1,
15 wherein the visionbased occupancy detection algorithm
using gradient back propagation approach is used in con-
junction with homogeneity constraint for detection of
imperfect homogenous circles with specific application
to head-top detection.
- 20 14. A system for occupancy detection as claimed in claim 1,
wherein the visionbased occupancy detection algorithm
using gradient back propagation approach is used in con-
junction with Centre Points Accumulation technique and
25 homogeneity criterion.
15. A method of detecting occupancy in a region exploiting
the centre points distribution for head-top circles in a
region, the method includes steps of:
30 modelling using occupancy detection algorithm using at
least one ceiling mounted camera;
calculating model-based predictions of occupancy within
the region by detecting human head-tops by locating cir-

cles in grayscale images wherein the circles are detected by back propagating the gradients in the image and applying thresholds on accumulated points thereby detecting circle centres.

5

16. A method for occupancy detection as claimed in claim 15, wherein the nearspherical shape of a human head top is used to accomplish occupancy detection in a circle detection-based framework.

10

17. A method for occupancy detection as claimed in claim 15, wherein the gradient back propagation approach includes the direction of the gradient vector, along with its magnitude, in circle detection framework.

15

18. A method for occupancy detection as claimed in claim 15, wherein the image captured by the ceiling camera is converted to grayscale and then filters are applied to find gradient vector at each point on the grayscale image.

20

19. A method for occupancy detection as claimed in claim 17, wherein the gradient vector is represented as (gr, θ) in the polar coordinate system, wherein gr is the magnitude of the gradient and θ is the direction.

25

20. A method for occupancy detection as claimed in claim 17, wherein for an object, the gradient vectors emerging out of the object along radial lines are propagated backwards using a fixed distance, converging at the centre of the object if the distance value selected is equal to the radius of the circle.

30

21. A method for occupancy detection as claimed in claim 15, wherein visionbased occupancy detection algorithm using gradient back propagation approach comprise the steps of:

5 converting the original RGB image to grayscale and apply two-dimensional gradient filters to find gradient vectors (r, θ) at each point on the image;
selecting a range of radius values $(r1, r2)$ to detect circles with radii lying in this range in the image,
10 where $r1$ & $r2$ are integer values representing the minimum and maximum radius values respectively in terms of number of pixels;
initializing a 3-D accumulator array (accm), of size $(p1, q1, r3)$ with zeros, where p and q are the width and
15 the height of the grayscale image respectively;
creating a vector $(rv, \theta + \pi)$ for each value of radius (rv) in the selected range $(r1, r2)$, where the said vector represents propagation of the gradient with distance rv in the reverse direction $(\theta + \pi)$ i.e back-propagation
20 of the gradient;
finding back-propagation vector (BPV) of the gradients for all points in the image and the projections of the BPV along the image axes i.e. (x, y) coordinates and round them to integral pixel values;
25 adding the said BPV vector to the corresponding pixel location; adding the value of gradient magnitude at pixel location $(p1, q1)$ in the grayscale image to the existing value at location $(p2, q2, rv)$ in the accumulator array (accm);
30 and
repeating the above steps for all pixels in the grayscale image and for all radius values $(r3)$.

22. A method for occupancy detection as claimed in claim 21, wherein the accumulator array (accm) gets populated with the gradient values of the original grayscale image.

5 23. A method for occupancy detection as claimed in claim 21, wherein the projections of the BPV along the image are calculated as:

$$x1 = [rv * \cos(\theta + \pi)]; \quad y1 = [rv * \sin(\theta + \pi)]$$

10 24. A method for occupancy detection as claimed in claim 21, wherein the accumulation values at all points within the said cylinder in the neighbourhood of a point in the accumulator array are integrated and is given by eqn :

$$15 \quad cpa(x, y, r) = \sum s \frac{accm(u, v, w)}{\sqrt{(x-u)^2 + (y-u)^2 + (r-w)^2}}$$

$$S = \{ (u, v, w) : \sqrt{(x-u)^2 + (y-v)^2} \leq th_{xy} \\ |r-w| \leq th_r \}$$

20 25. A method for occupancy detection as claimed in claim 21, wherein a suitable threshold is applied to each 2-D (x, y) plane in accumulator array to detect corresponding circles of radii between (r1, r2) and the choice of threshold depends on the circularity of the object to be
25 detected.

26. A method for occupancy detection as claimed in claim 25, wherein for near perfect circles in the image, a high value of threshold is preferable, whereas, if the cir-
30 cles in the original image are imperfect or incomplete, a low value for threshold is selected.

27. A method for occupancy detection as claimed in claim 15,
wherein the visionbased occupancy detection algorithm
using gradient back propagation approach is used in con-
5 junction with Centre Points Accumulation technique for
detection of imperfect circles with specific application
to head-top detection.

28. A method for occupancy detection as claimed in claim 15,
10 wherein the visionbased occupancy detection algorithm
using gradient back propagation approach is used in con-
junction with homogeneity criterion for detection of im-
perfect homogenous circles with specific application to
head-top detection.

15 29. A method for occupancy detection as claimed in claim 15,
wherein the visionbased occupancy detection algorithm
using gradient back propagation approach is used in con-
junction with Centre Points Accumulation technique and
20 homogeneity criterion.

30. A system for detecting occupancy in a region using cen-
tre points distribution for head-top circles in a re-
25 gion, the system includes means for detecting each of
the plurality of head top circles in a particular re-
gion;
means for calculating model-based detections of occu-
pancy within the region based on state equations that
model occupancy of each region,
30 means for detecting human head-tops by locating circles
in grayscale images, wherein the circles are detected by
back-propagating the gradients in the image and applying
thresholds on accumulated points thereby detecting cir-

cle centres wherein the points of the potential centre candidates are accumulated in a 3-D accumulator and after accumulation, a suitable threshold is applied to each 2-D (x,y) plane in accumulator array to detect circles of corresponding radii.

31. A computer readable storage medium encoded with a machine-readable computer program code for generating occupancy detection for a region, the computer readable storage medium including instructions for causing a controller to implement the method as claimed in claims 15 - 28.

32. The computer program product for occupancy detection exploiting the centre point's distribution for head top circles in a region, which includes instructions for calculating model-based detections of occupancy within the region based on state equations that model occupancy of the region;

detecting human head-tops by locating circles in gray-scale images, further the circles are detected by back-propagating the gradients in the image and applying thresholds on accumulated points thereby detecting circle centres wherein the points of the potential centre candidates are accumulated in a 3- D accumulator and after accumulation, a suitable threshold is applied to each 2-D (x,y) plane in accumulator array to detect circles of corresponding radii.

33. Use of a method according to any of claims 15 - 29 for modelling of cost effective and power efficient indoor/outdoor scenarios and in lightning, HVAC control.

FIG 1

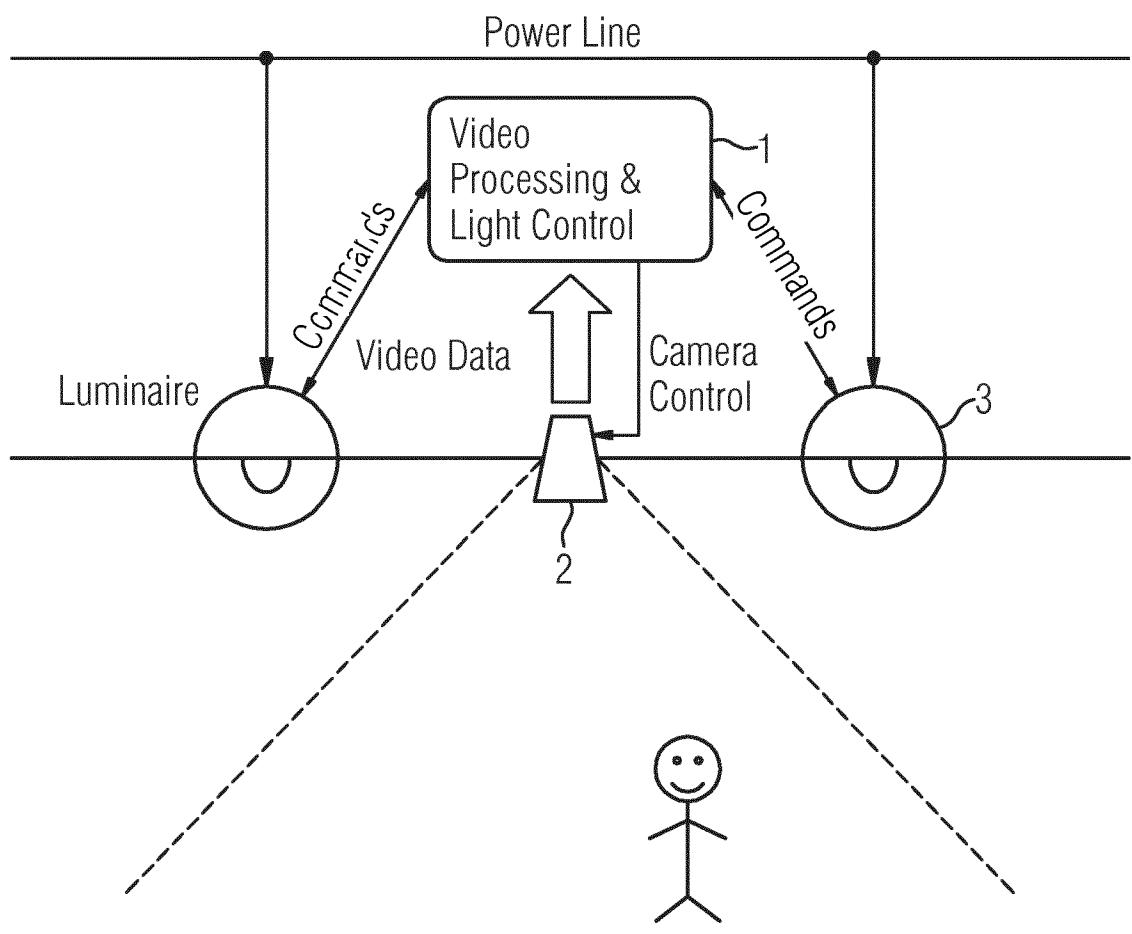
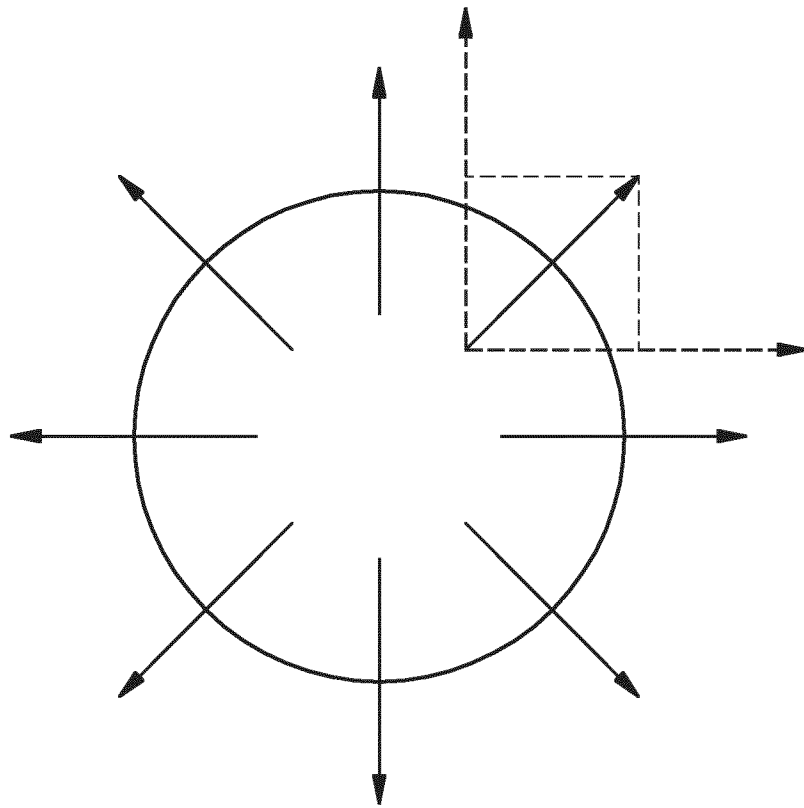
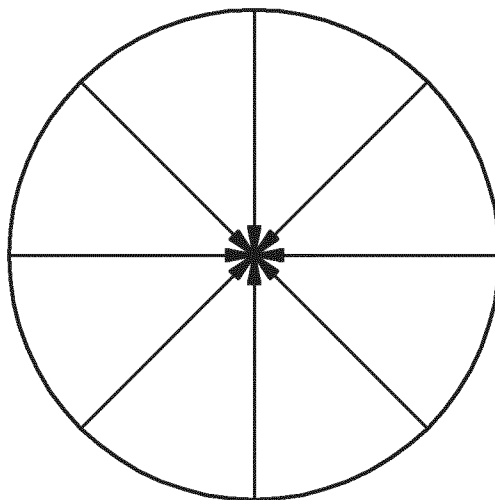


FIG 2



(a) Gradient vector for circles



(b) Back propagation

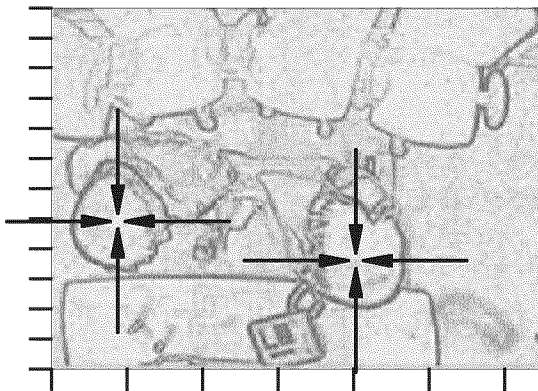
FIG 3



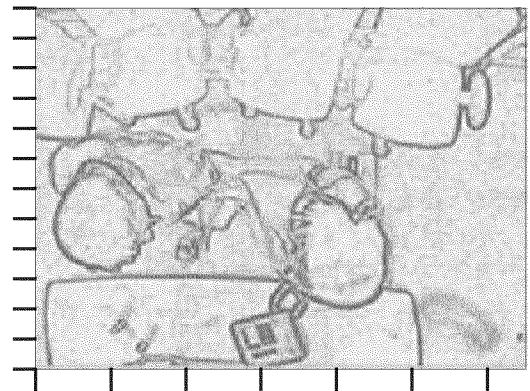
Original Image (coloured)



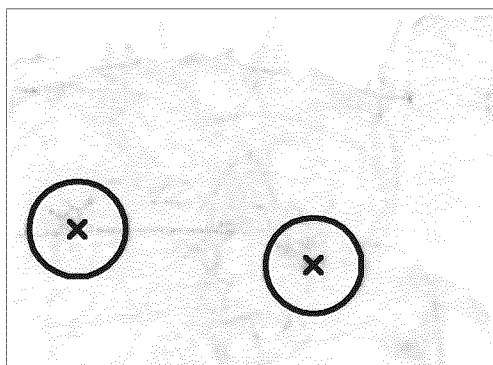
Convert to grayscale



Back-propagate gradients



Compute gradients



Find centers applying threshold



Output Image (coloured)

FIG 4

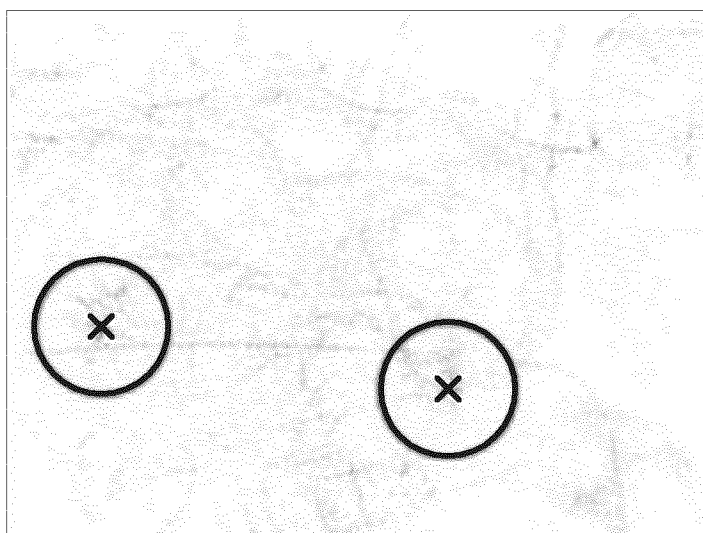
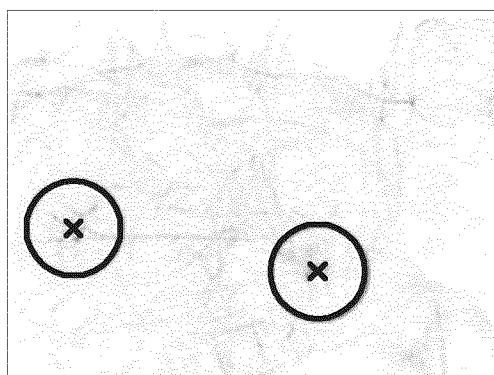
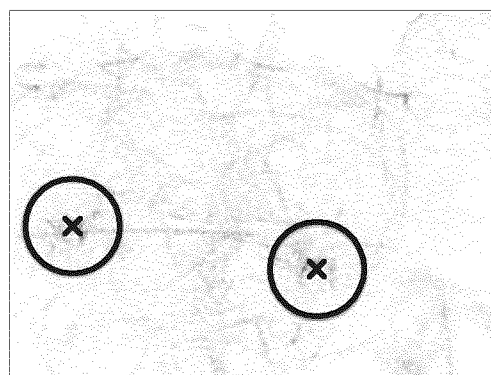
Back Propagation ($r=28$ pixels)Back Propagation ($r=32$ pixels)Back Propagation ($r=36$ pixels)

FIG 5

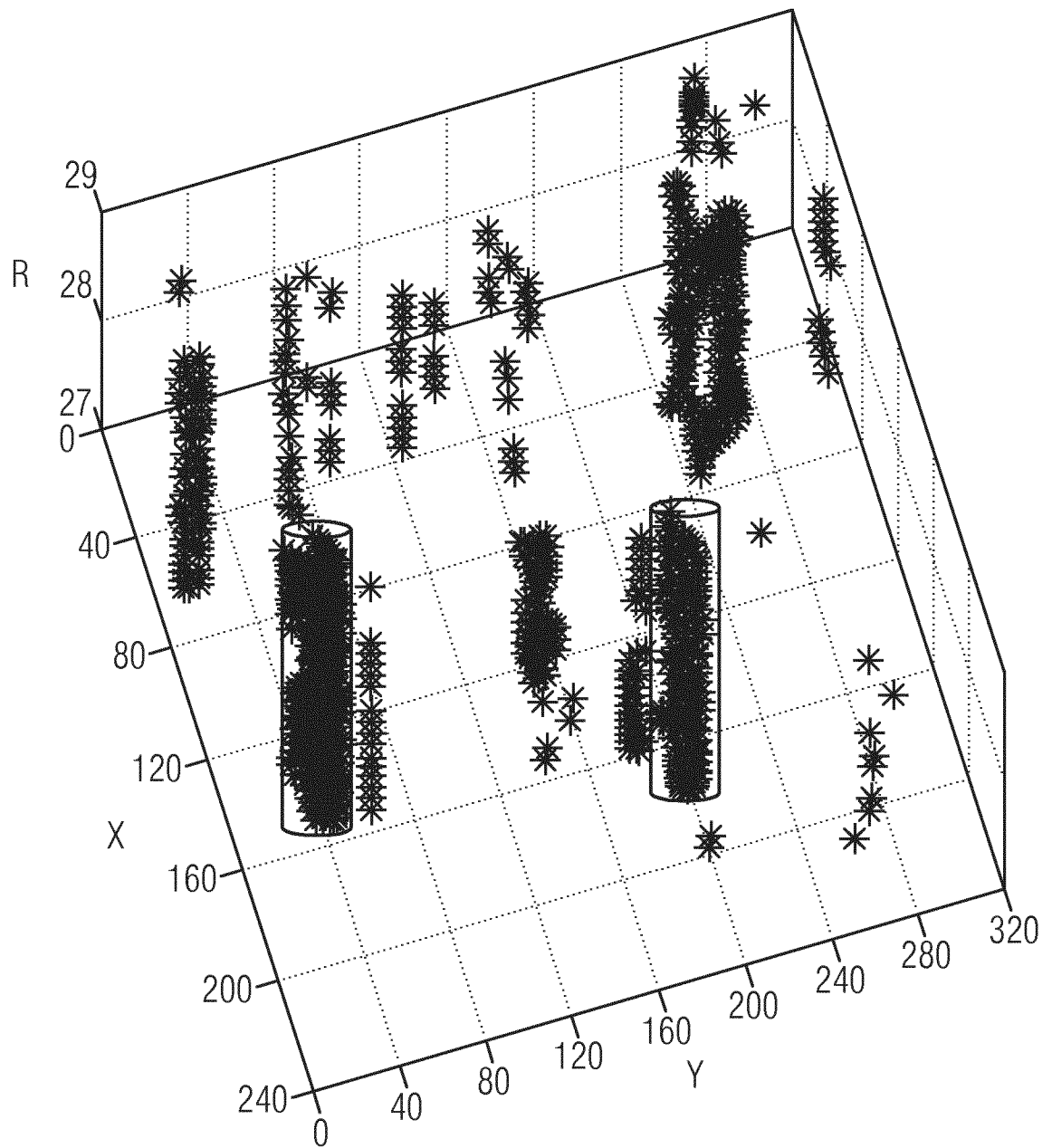


FIG 6

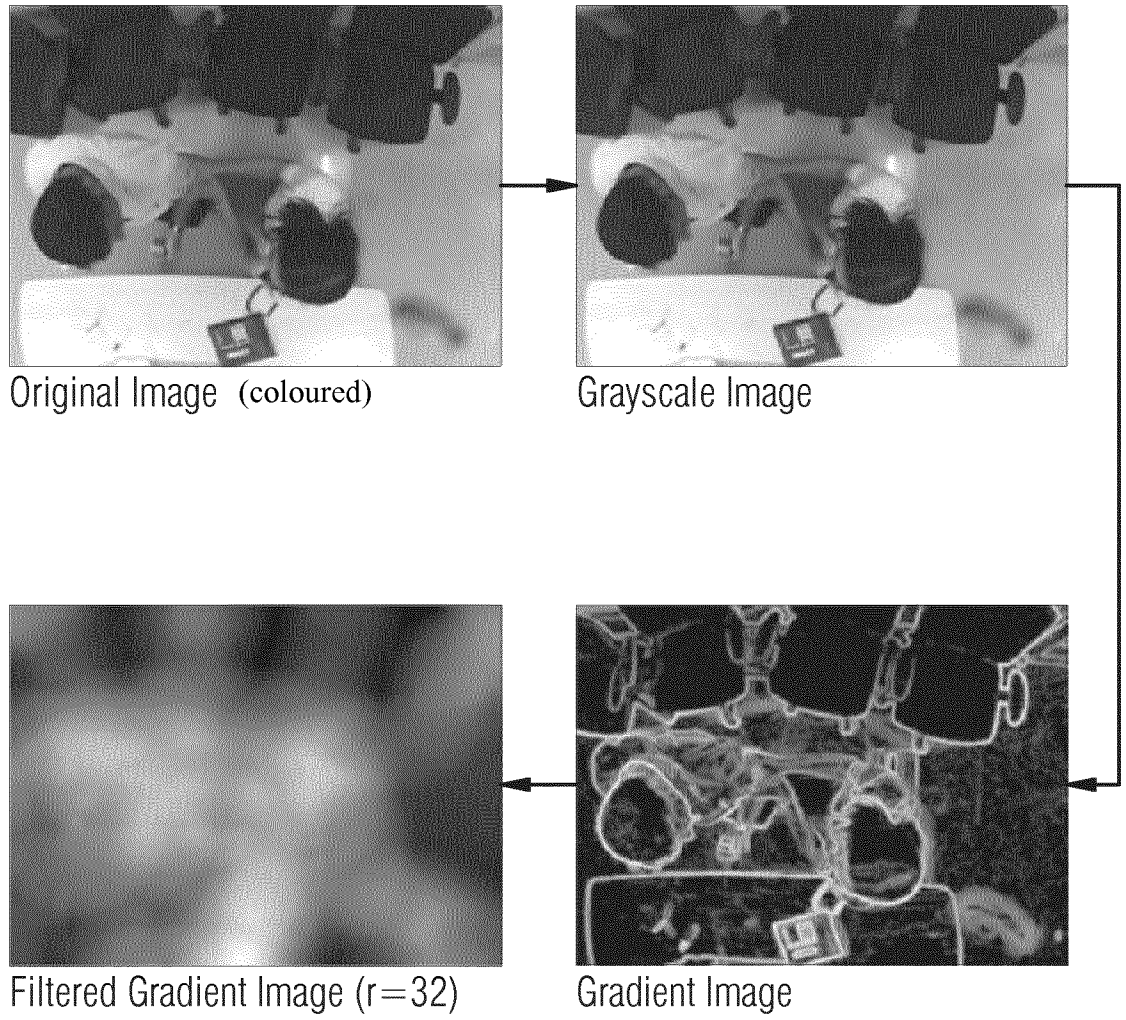
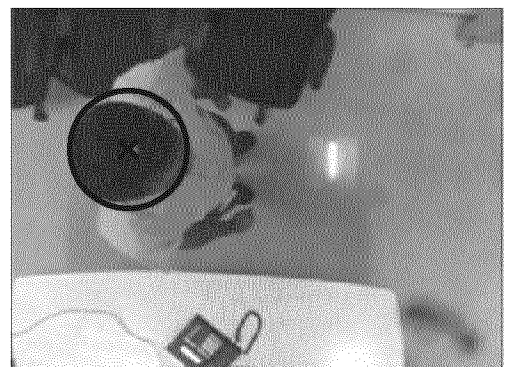
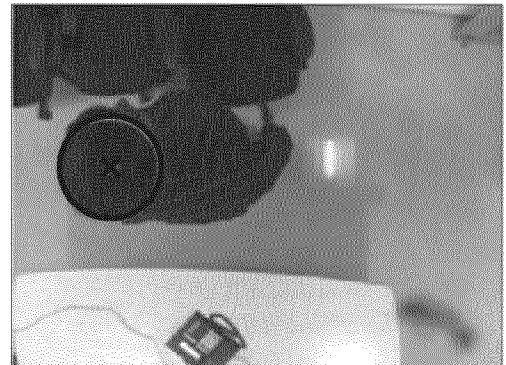
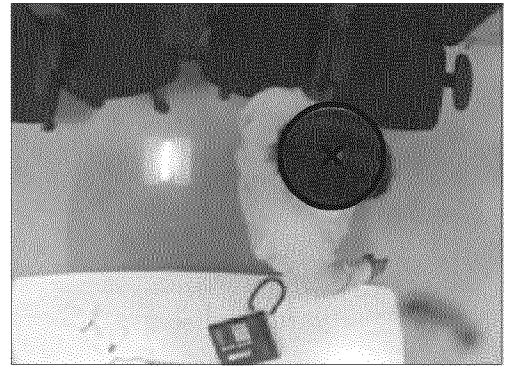
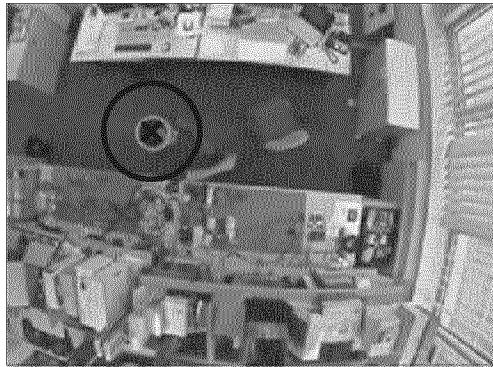


FIG 7



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/064312

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06K9/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06K G06T G08B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Hong Liu ET AL: "DETECTING PERSONS USING HOUGH CIRCLE TRANSFORM IN SURVEILLANCE VIDEO", VISAPP 2010, 17 May 2010 (2010-05-17), XP055079840, Retrieved from the Internet: URL: http://sourcedb.ict.cas.cn/cn/ictthesi/s/201103/P020110314771243256015.pdf [retrieved on 2013-09-18]	1-23, 25-33
Y	sect 1, 2, 3 ----- -/--	33



Further documents are listed in the continuation of Box C.



See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

18 September 2013

Date of mailing of the international search report

26/09/2013

Name and mailing address of the ISA/

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Authorized officer

Darolti, Cristina

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/064312

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	YUEN H ET AL: "Comparative study of Hough Transform methods for circle finding", IMAGE AND VISION COMPUTING, ELSEVIER, GUILDFORD, GB, vol. 8, no. 1, 1 February 1990 (1990-02-01), pages 71-77, XP026655739, ISSN: 0262-8856, DOI: 10.1016/0262-8856(90)90059-E [retrieved on 1990-02-01] page 170	1-33
Y	----- US 6 486 778 B2 (MAHLER HANSJURG [CH] ET AL MAHLER HANSJUERG [CH] ET AL) 26 November 2002 (2002-11-26) col.2 -----	33

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2013/064312

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		EP 1109141 A1	20-06-2001
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		IL 139611 A	19-06-2005
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