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## Method, system and computer readable media for object detection coverage estimation


### Abstract

Methods, systems and computer readable medium for object detection coverage estimation are provided. The system for object detection coverage estimation includes a camera and a processing means. The processing means is coupled to the camera to receive image data acquired by the camera, the image data including a detected object. The processing means is configured to determine a spatial coverage of the detected object based on detected object metadata associated with the detected object in the image data received from the camera.



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## Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) The present application is a continuation application of U.S. patent application Ser. No. 17/439,072 filed on Sep. 14, 2021, which is a National Stage Entry of international application PCT/JP2020/013016 filed on Mar. 24, 2020, which claims the benefit of priority from Singaporean Patent Application 10201902705S filed on Mar. 26, 2019, the disclosures of all of which are incorporated in their entirety by reference herein.

TECHNICAL FIELD
(1) The present invention generally relates to computer vision, and more particularly relates to methods and systems for object detection coverage estimation.
BACKGROUND ART
(2) Computer vision is an interdisciplinary field that includes methods for acquiring, processing and analysing digital images or videos to extract real world information for further decision. Object detection technologies involve using computer vision algorithms and image processing to provide computers the ability to identify real world object from digital images.
(3) To detect an object in a digital image, computer processing scans an image segment by segment while performing pattern matching for each part of the target image. Image object detection processes are computer power intensive. As resolution per image increases (e.g., FHD, 4K),

increased computer power is required for better accuracy as well as to reduce misdetection at higher frame rate (fps).
(4) Conventional methods to reduce computing power requirements of image object detection include lowering the input image sequence frame rate (e.g., lowering from 15 fps to 5 fps), reducing image resolution by only processing identified areas of interest, and scaling down original image resolution (e.g., reducing 4K resolution to FHD resolution). Additional conventional methods for reducing computing power requirements of image object detection include limiting a detected object size (e.g., pixel size) by a specific minimum or maximum value or limiting detection objects by a specific maximum number of detections. Most object detection systems implement one or more of these conventional methods with configurations for different setup requirements and system constraint trade-offs.
SUMMARY OF INVENTION
Technical Problem
(5) However, while most computer vision software allows trade-offs to be made by reconfiguring the software within system constraints in order to fulfil the requirements, this reconfiguring affects the effective processing coverage as the system can no longer cover the full area of a camera's view. This has become one of the challenges in deploying computer vision solutions as it is hard to provide estimated real-world spatial coverage information for better decision making as such estimated coverage information is very dependent on real-world criteria. Thus, what is needed is methods and systems for object detection coverage estimation which visualizes real-world spatial coverage of detected objects in a camera's view to provide computer vision which is aware of system constraints and requirement trade-offs for better decision making. Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background of the disclosure.
Solution to Problem
(6) According to at least one embodiment of the present invention, a method for object detection coverage estimation is provided. The method includes acquiring image data from a camera, the image data comprising at least one detected object. The method further includes determining a spatial coverage of the at least one detected object in response to detected object metadata associated with the at least one detected object in the image data acquired by the camera.
(7) According to another embodiment of the present invention, a system for object detection coverage estimation is provided. The system includes a camera and a processing means. The processing means is coupled to the camera to receive image data acquired by the camera, the image data comprising at least one detected object. The processing means is further configured to determine a spatial coverage of the detected object based on detected object metadata associated with the at least one detected object in the image data received from the camera.
(8) And according to yet another embodiment, a computer readable medium for performing object detection coverage estimation is provided. The computer readable medium has instructions stored thereon for a processing means to determine a spatial coverage of at least one detected object from two-dimensional image data acquired by a camera. The spatial coverage of the at least one detected object is determined in response to detected object metadata in the two-dimensional image data associated with the at least one detected object in the image data by calculating the spatial coverage in three-dimensional coordinates of the at least one detected object in response to the two-dimensional image metadata associated with the detected object in the image data acquired by the camera and, further, in response to parameters of the camera using a pinhole camera model.

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## Description

BRIEF DESCRIPTION OF DRAWINGS

(1) The accompanying figures, where like reference numerals refer to identical or functionally similar elements throughout the separate views and which together with the detailed description below are incorporated in and form part of the specification, serve to illustrate various embodiments and to explain various principles and advantages in accordance with a present embodiment.

(2) FIG. **1**A depicts top planar views of detected objects.

(3) FIG. **1**B depicts top planar views of detected objects.

(4) FIG. **1**, comprising FIGS. **1**A and **1**B, depicts top planar views of detected objects, wherein FIG. **1**A highlights large objects in the foreground and FIG. **1**B highlights smaller objects in the background.

(5) FIG. **2** illustrates a method for object detection coverage estimation in accordance with present embodiments.

(6) FIG. **3** depicts a flow diagram of a method for object detection coverage estimation in accordance with the present embodiments.

(7) FIG. **4** depicts a block diagram of a system for object detection coverage estimation in accordance with the present embodiments.

(8) FIG. **5**A depicts a method for calculating three dimensional spatial coverage of an object from two-dimensional image data in accordance with the present embodiments.

(9) FIG. **5**B depicts a method for calculating three dimensional spatial coverage of an object from two-dimensional image data in accordance with the present embodiments.

(10) FIG. **5**C depicts a method for calculating three dimensional spatial coverage of an object from two-dimensional image data in accordance with the present embodiments.

(11) FIG. **5**D depicts a method for calculating three dimensional spatial coverage of an object from two-dimensional image data in accordance with the present embodiments.

(12) FIG. **5**E depicts a method for calculating three dimensional spatial coverage of an object from two-dimensional image data in accordance with the present embodiments.

(13) FIG. **5**, comprising FIGS. **5**A to **5**E, depicts a method for calculating three dimensional spatial coverage of an object from two-dimensional image data in accordance with the present embodiments, wherein FIG. **5**A depicts a top planar view of a camera view of detected objects, FIG. **5**B depicts a side planar view of the camera and objects detected by the camera, FIG. **5**C depicts a top planar view of the camera and objects detected by the camera, FIG. **5**D depicts an exemplary object height for use in the calculation of the spatial coverage, and FIG. **5**E a perspective view diagram of an exemplary calculation of the three-dimensional spatial coverage of the object.

(14) FIG. **6**A depicts top planar views of coverage area estimation in accordance with the present embodiments.

(15) FIG. **6**B depicts top planar views of coverage area estimation in accordance with the present embodiments.

(16) FIG. **6**, comprising FIGS. **6**A and **6**B, depicts top planar views of coverage area estimation in accordance with the present embodiments, wherein FIG. **6**A depicts a top planar view of a nearest and furthest lines of the coverage area estimation and FIG. **6**B depicts a top planar view of contour detection estimation of a dilated view of objects.

(17) FIG. **7**A depicts top planar views of two aspects of object detection estimation in accordance with the present embodiments.

(18) FIG. **7**B depicts top planar views of two aspects of object detection estimation in accordance with the present embodiments.

(19) And FIG. **7**, comprising FIGS. **7**A and **7**B, depicts top planar views of two aspects of object detection estimation in accordance with the present embodiments, wherein FIG. **7**A depicts an

estimation of detected object spatial coverage based on detected object metadata and FIG. **7**B depicts an estimation of camera blind spots based on detected object metadata.

(20) Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been depicted to scale.

DESCRIPTION OF EMBODIMENTS

(21) The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Furthermore, there is no intention to be bound by any theory presented in the preceding background of the invention or the following detailed description. It is the intent of the present embodiment to present methods and systems for object detection coverage estimation which require less computing time than conventional methods and systems without the required trade-offs and/or constraints of such conventional methods and systems. In accordance with present embodiments, methods and systems to object detection coverage estimation can be used to determine detected object blind spots associated with the detected object.

(22) Referring to FIGS. **1**A and **1**B, illustration **100**, **150** depicts a top planar view of an area **110**, the area **110** representing a camera view from a camera located at position **120**. The area **110** includes several foreground objects **130** and several background objects **140**. In accordance with image object detection processes, sometimes detected objects **130** are of interest to processing of images acquired from the camera located at the position **120** and sometimes detected objects **140** are of interest. In order to detect objects **130** or objects **140**, it is necessary to estimate object detection spatial coverage **135**, **145**.

(23) Such estimation, however, is difficult in conventional computer vision systems because, while most computer vision software allows trade-offs to be made through configuration within system constraints to fulfil requirement, such trade-offs affect effective processing of detected object coverage. This has become one of the challenges in deploying computer vision solutions as it is hard to provide estimated real world spatial coverage information for better decision making. Referring to FIG. **2**, an illustration **200** depicts views **210**, **230**, **250** of essential elements of methods and systems in accordance with present embodiments which advantageously estimate object detection spatial coverage using camera metadata and information from acquired images.

(24) The view **210** of present methods and systems depicts image acquisition of a two-dimensional camera view **215** (i.e., input of object reference points in a two dimensional coordinate system). Persons **216**, **218**, **220**, **222**, **224** are detected objects having respective object reference points **217**, **219**, **221**, **223**, **225** in the camera view **215**. In accordance with present embodiments for object coverage estimation, a two dimension (2D) to three-dimension (3D) mapping process **228** recreates virtual spatial coverage of the detected objects (people **216**, **218**, **220**, **222**, **224**) from the metadata associated with the detected objects and from parameters of the camera **240** in order to determine the object reference points in a three-dimensional coordinate system. The virtual spatial coverage of the detected objects is shown in the view **230** as a side view **235** of image capture by the camera **240** having an image view **245** of the area **215**.

(25) Processing, in accordance with the present embodiments performs covered area estimation **248** as shown in the view **250**. The view **250** depicts a calculated coverage area **252** in a top view coordinate system where the coverage area **252** has a front boundary L**1 254** and a back boundary L**2 256** which includes persons **216**, **218**, **220**.

(26) Referring to FIG. **3**, a flow diagram **300** depicts a method for object detection coverage estimation in accordance with the present embodiments. The method includes a data collection phase **302** and an analytic configuration phase **304**. In the data collection phase **302**, image data is acquired **310** from the camera **240**. The image data includes at least one detected object. Next, object detection is performed **312** on the acquired image data to generate two-dimensional detected object metadata. The detected object metadata is stored **314** in a data storage device **320** and the data collection phase returns to the image acquisition step **310**.

(27) The analytic configuration phase **304** retrieves **330** the detected object metadata from the data storage device **320**. If the computer vision includes multiple cameras **240**, the retrieved detected object metadata is for a selected one of the cameras **240**. The spatial coverage of the detected object(s) is determined **332** from the retrieved detected object metadata (i.e., the detected object two-dimensional image metadata) and camera configuration information (i.e., parameters of the camera). Determining the spatial coverage of the detected object(s) includes calculating spatial coverage in three-dimensional coordinates of the detected object(s) in response to the two-dimensional image metadata associated with the detected object(s) in the image data acquired **310** by the camera **240** and in response to the parameters of the camera using a pinhole camera model. The coverage area, including the estimated detected object coverage area, is then displayed **334**.
(28) In addition to estimating detected object spatial coverage, it is important to also determine blind spots associated with detected objects in for computer vision systems to better understand spatial views acquired by cameras **240**. In accordance with present embodiments, the calculation step **332** may further include determining a detected object blind spot within the image data associated with each of the detected object(s) in response to the detected object metadata. The step **336** would also include determining quality of camera coverage in response to the detected object blind spot associated with each of the detected objects after displaying **334** the spatial coverage of the detected object(s) and the detected object blind spot(s) associated with each of the detected object(s).
(29) FIG. **4** depicts a block diagram **400** of a system for object detection coverage estimation in accordance with the present embodiments. The system includes one or more cameras **240** for acquiring computer vision images. While the description of present embodiments has depicted a camera **240** and focused on acquisition of images form the camera **240**, those skilled in the art will realize that a computer vision system typically includes many cameras. Systems and methods in accordance with the present embodiments can accommodate multiple cameras and detected object metadata acquired from each of the cameras during a data collection phase **302** for each camera can be centrally stored in the data storage device **320**.
(30) A processing means **402** is coupled to the camera(s) **240** to receive image data **404** acquired by the camera **240**. The processing means **402** includes a first processing device **406** for receiving the image data **404** and performing the data collection phase **302** processing for each camera **240**. The processing means **402** also includes a second processing device for performing the analytic configuration phase **304** processing. The first processing device **406** can directly provide **410** the detected object metadata to the second processing device **408** or, as described in regards to FIG. **3** above, provide **412** the detected object metadata to the storage device **320** for later retrieval **414** by the second processing device. Those skilled in the art will realize that the processing means **402** may be one server with multiple processors or may include multiple servers with multiple first processing devices **406** and/or multiple second processing devices **408**. Thus methods and systems for object detection coverage estimation in accordance with present embodiments can provide a system configuration which can include a single second processing device **408** provided for multiple first processing devices **406**.
(31) The second processing device **408** is coupled to a display **416** for display of the spatial coverage of the detected object(s) for determining the quality of camera coverage and for observing the detected object(s). The second processing device **408** is also coupled to a user input device **418** for receiving user input for determining the quality of camera coverage and/or for receiving the inputted configurations **338**. As described above, the second processing device **408** can determine the estimated coverage are for the detected object(s) as well as the detected object blind spot(s) within the image data associated with each of the detected object(s) in response to the detected object metadata.
(32) In accordance with present embodiments, the first processing device **406** generates the detected object metadata by performing **312** object detection on the acquired image data. The

second processing means **408** is configured to use a pinhole camera model to calculate the spatial coverage in three-dimensional coordinates of the detected object(s) from the two-dimensional image metadata associated with the detected object(s) and parameters of the camera. FIGS. **5**A to **5**E depict a method for calculating three-dimensional spatial coverage of the detected object(s) from two dimensional image data in accordance with the present embodiments.

(33) Referring to FIG. **5**A, a top planar view **500** depicts a camera view of detected objects **502**, **504**, **506** having respective reference points in camera coordinates (u, v) of projection points of the detected object pixels in the acquired image data: (u1, v1), (u2, v2) and (u3, v3). Referring to a real-world spatial coordinate system XYZ, FIG. **5**B depicts a side planar view **520** of the camera **240** and the objects (persons **502**, **504**, **506**) detected by the camera **240** in the plane defined by the axis X and the axis Z and FIG. **5**C depicts a top planar view **540** of the camera **240** and the objects **502**, **504**, **506** detected by the camera **240** in the plane defined by the axis X and the axis Y. FIG. **5**D shows a side planar view **560** of reference dimension **562**, chosen in accordance with one of the present embodiments as a typical head height of a human (1.70 meters).

(34) In accordance with present embodiments for object coverage estimation, a two-dimension (2D) to three-dimension (3D) mapping process **228** recreates virtual spatial coverage of the detected objects (people **216**, **218**, **220**, **222**, **224**) from the metadata associated with the detected objects and from parameters of the camera **240** in order to determine the object reference points in a three-dimensional coordinate system. In accordance with one aspect of the present embodiments, a pinhole camera model is used as the mapping process. Referring to FIG. **5**E, a perspective view **580** depicts an exemplary pinhole camera model mapping process which creates a virtual three-dimensional view by projecting three dimensional points generated from the metadata of the detected objects into the three-dimensional coordinate system using a perspective transformation as shown in Equations 1 to 5 wherein an input to the transformation includes the reference points of the detected objects in camera coordinates (u, v) and the reference dimension **562** (FIG. **5**D) which is an estimated height of a detected object in the real-world coordinate Z. The output of the transformation is the set of real-world coordinates (X, Y).

(35) $[\begin{matrix} x \\ y \\ z \end{matrix}] = R[\begin{matrix} X \\ Y \\ Z \end{matrix}] + t$ (1) $x' = x/z$ (2) $y' = y/z$ (3) $u = f_x * x' + c_x$ (4)

$v = f_y * y' + c_y$ (5)

where X, Y and Z are the coordinates of a three-dimensional point P **582** in the real-world spatial coordinate system represented by x **584**, y **585**, and z **586** (where z **586** is typically the optical axis of the acquired image), u **588** and v **590** are coordinates of the projection points of the detected object pixels in the acquired image data, f.sub.x and f.sub.y are focal length parameters of the camera **240** (i.e., intrinsic camera parameters) expressed in pixel units, c.sub.x and c.sub.y which are coordinates of a principal point **592** in the acquired image, usually at the image center, x′ **590**, y′ **591**, and z′ **592**, t is extrinsic parameters of the camera **240** (for example, a matrix of extrinsic parameters of the camera **240**), and R is another matrix of extrinsic parameters referred to as a joint rotational translation matrix. The joint rotational translation matrix is used to describe rigid motion of an object in front of the still camera **240** or, vice versa, motion of the camera **240** around a static scene. In other words, R translates the coordinates of a point (e.g., the point P **582**) in the real-world spatial coordinate system to a coordinate system fixed with respect to the camera (i.e., the coordinate system x **584**, y **585**, z **586**).

(36) Referring to FIGS. **6**A and **6**B, top planar views **600**, **650** depict results of detected object coverage area estimation in accordance with the present embodiments. The view **600** depicts a camera view **602** wherein systems and methods in accordance with the present embodiments use a nearest and furthest line estimation technique to determine a spatial coverage estimation of a coverage area **604** for a first detected object **606**, a second detected object **608** and a third detected

object **610**. The spatial coverage area estimation **604** is bounded by a nearest line **612** passing through the first detected object **606** and a furthest line **614** passing through the third detected object **610**.

(37) The view **650** depicts a camera view **652** wherein systems and methods in accordance with the present embodiments use a contour detection estimation of object dilated view technique to determine spatial coverage estimations of first, second and third detected objects **660**, **662**, **664**. The contour detection estimation of object dilated view includes both morphological transformation (i.e., dilation) **670**, **672**, **674** of the detected objects **660**, **662**, **664** as well as contour detection **654**, **656**, **658** of the detected objects **660**, **662**, **664**.

(38) FIGS. **7**A and **7**B depict top planar views of two aspects of object detection estimation in accordance with the present embodiments. FIG. **7**A depicts a view **700** of one variation of the estimation of detected object spatial coverage **710**, **720**, **730** based on detected object metadata in accordance with the present embodiments. In accordance with a second aspect of the present embodiments, FIG. **7**B depicts a view **750** of an estimation of camera blind spots **752**, **754** based on detected object metadata.

(39) Thus, it can be seen that the present embodiments provide methods and systems for object detection coverage estimation which advantageously visualizes real-world spatial coverage of detected objects in a camera's view to provide computer vision which is aware of system constraints and requirement trade-offs for better decision making. Not only spatial coverage of detected objects can be estimated in accordance with present embodiments, but detected object blind spots can also be identified. Computer vision systems utilizing methods and systems in accordance with present embodiments are more robust and require less time to estimate coverage area of detected objects thereby improving response time, decision making and accuracy.

(40) While exemplary embodiments have been presented in the foregoing detailed description of the invention, it should be appreciated that a vast number of variations exist. It should further be appreciated that the exemplary embodiments are only examples, and are not intended to limit the scope, applicability, operation, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the invention, it being understood that various changes may be made in the function and arrangement of steps and method of operation described in the exemplary embodiment without departing from the scope of the invention as set forth in the appended claims.

(41) This application is based upon and claims the benefit of priority from Singapore patent application No. 10201902705S, filed on Mar. 26, 2019, the disclosure of which is incorporated herein in its entirety by reference.

## Claims

1. A system comprising: a memory storing instructions; and a processor connected to the memory and configured to execute the instructions to: receive two-dimensional image metadata of a detected object detected from image data, the detected object being a person; estimate spatial coverage of the detected object in three-dimensional space based on the received two-dimensional image metadata, camera configuration information of a camera that captured the image data, and information on a height of a predetermined person, the two-dimensional image metadata indicating coordinates of a top of a head of the person in the image data, the camera configuration information including information on an optical axis of the image data; determine a blind spot associated with the detected object in the image data based on the two-dimensional image metadata; output the estimated spatial coverage and the blind spot associated with the detected object; determine a spatial coverage area including the spatial coverage of the detected object bounded by a nearest line passing through the detected object closest to the camera and a furthest line passing through the

detected object farthest from the camera; determine a coverage between the camera and the nearest line and a coverage that is away from the camera relative to the furthest line as the blind spot; and output the determined spatial coverage area and the blind spot.

2. The system according to claim 1, wherein the processor is configured to execute the instructions to determine quality of camera coverage based on the blind spot associated with each detected object.

3. The system according to claim 1, wherein the processor is configured to execute the instructions to output the estimated spatial coverage as object detection coverage.

4. The system according to claim 1, wherein the processor is configured to execute the instructions to display the estimated spatial coverage and the blind spot on a display.

5. The system according to claim 1, wherein the processor is configured to execute the instructions to determine the spatial coverage of the detected object by calculating spatial coverage in three-dimensional coordinates of the detected object based on the two-dimensional image metadata associated with the detected object in the image data and based on the camera configuration information of the camera using a pinhole camera model.

6. The system according to claim 1, wherein the processor is configured to execute the instructions to acquire the image data captured by the camera, generate the two-dimensional image metadata by performing object detection on the acquired image data, and store the generated two-dimensional image metadata in a data storage device.

7. The system according to claim 6, wherein the processor is configured to execute the instructions to retrieve the two-dimensional image metadata stored in the data storage device.

8. The system according to claim 1, wherein the processor is configured to execute the instructions to determine quality of camera coverage based on the spatial coverage of the detected object.

9. The system according to claim 8, further comprising a display coupled to the processor, wherein the processor is configured to execute the instructions to forward data to the display to display the spatial coverage of the detected object for determining the quality of camera coverage.

10. The system of claim 1, further comprising a user input device for receiving user input for determining quality of camera coverage.

11. The system according to claim 1, further comprising a display coupled to the processor, wherein the processor is configured to execute the instructions to forward data to the display to display the spatial coverage of the detected object and the detection blind spot associated with each of the detected object for determining quality of camera coverage.

12. A method performed by a computer and comprising: receiving two-dimensional image metadata of a detected object detected from image data, the detected object being a person; estimating spatial coverage of the detected object in three-dimensional space based on the received two-dimensional image metadata, camera configuration information of a camera that captured the image data, and information on a height of a predetermined person, the two-dimensional image metadata indicating coordinates of a top of a head of the person in the image data, the camera configuration information including information on an optical axis of the image data; determining a blind spot associated with the detected object in the image data based on the two-dimensional image metadata; outputting the estimated spatial coverage and the blind spot associated with the detected object; determining a spatial coverage area including the spatial coverage of the detected object bounded by a nearest line passing through the detected object closest to the camera and a furthest line passing through the detected object farthest from the camera; determining a coverage between the camera and the nearest line and a coverage that is away from the camera relative to the furthest line as the blind spot; and outputting the determined spatial coverage area and the blind spot.

13. A non-transitory computer readable medium storing a program executable by a computer to perform processing comprising: receiving two-dimensional image metadata of a detected object detected from image data, the detected object being a person; estimating spatial coverage of the

detected object in three-dimensional space based on the received two-dimensional image metadata, camera configuration information of a camera that captured the image data, and information on a height of a predetermined person, the two-dimensional image metadata indicating coordinates of a top of a head of the person in the image data, the camera configuration information including information on an optical axis of the image data; determining a blind spot associated with the detected object in the image data based on the two-dimensional image metadata; outputting the estimated spatial coverage and the blind spot associated with the detected object; determining a spatial coverage area including the spatial coverage of the detected object bounded by a nearest line passing through the detected object closest to the camera and a furthest line passing through the detected object farthest from the camera; determining a coverage between the camera and the nearest line and a coverage that is away from the camera relative to the furthest line as the blind spot; and outputting the determined spatial coverage area and the blind spot.