viewing angles, and the like can easily change the results. Logo type images can be present in multiple places within the scene (i.e., a logo can be on a ball, a T-shirt, a hat, or a coffee mug) and the object recognition is by inference. The visual parameters of the object must be converted to mathematical parameters at great effort. Flexible objects that can change their shape are problematic as each possible shape must be included in the database. There is always inherent ambiguity as similarly shaped objects may be misidentified as the object of interest.

Technique 6: The quality of the training data set determines the success of the method. For each object to be recognized/classified many training images are needed. The same occlusion and flexible object shape limitations as for Technique 5 apply. There is a need to train each class of material with thousands or more of images.

Technique 7: This technique works when the scene is pre-organized, but this is rarely practical. If the object of interest leaves the scene or is completely occluded the object could not be recognized unless combined with other techniques above.

Apart from the above-mentioned shortcomings of the already existing techniques, there are some other challenges worth mentioning. The ability to see a long distance, the ability to see small objects or the ability to see objects with enough detail all require high resolution imaging systems, i.e. high-resolution camera, lidar, radar etc. The high-resolution needs increase the associated sensor costs and increase the amount of data to be processed.

For applications that require instant responses like autonomous driving or security, the latency is another important example. The amount of data that needs to be processed determines if edge or cloud computing is appropriate for the application, the latter being only possible if data loads are small. When

edge computing is used with heavy processing, the devices operating the systems get bulkier and limit ease of use and therefore implementation.

Since ambient lighting conditions as well as active light probes/sources are important parts of the data collected in image analysis for object recognition, it was an object of the present disclosure to provide a possibility to combine the need for specialized light probes associated with an imaging sensor device with the need for visually pleasant ambient lighting into a single lighting device. Furthermore, this design lowers the sensitivity of the computer vision application to ambient lighting in general, as now the specialized light probe intensity is directly related to ambient lighting intensity and, in some cases, enable chemistry-/physics-based recognition techniques.

Thus, a need exists for systems and methods that are suitable for simplifying requirements for object recognition via a computer vision application.

Summary

The above-mentioned objects are solved by the system and the method with the features of the respective examples herein. Further examples are presented by the following description and the respective examples.

In an aspect, there is provided a system for object recognition via a computer vision application, the system (100) comprising at least the following components:

- an object (130) to be recognized, the object having object specific reflectance and luminescence spectral patterns,
- a light source (110) which is composed of at least two illuminants (111, 112, 113, 114, 115) and is configured to illuminate a scene including the object to be recognized by switching between the at least two illuminants, wherein at least one of the at least two illuminants is based on at least one solid-state lighting system,

- a sensor (120) which is configured to measure radiance data of the scene including the object when the scene is illuminated by the light source,
- a data storage unit (150) which comprises luminescence spectral patterns together with appropriately assigned respective objects,
- a data processing unit (140) which is configured to extract the object specific luminescence spectral pattern of the object to be recognized out of the radiance data of the scene and to match the extracted object specific luminescence spectral pattern with the luminescence spectral patterns stored in the data storage unit, and to identify a best matching luminescence spectral pattern and, thus, its assigned object.

In another aspect, there is provided a method for object recognition via a computer vision application, the method comprising at least the following steps:

- providing an object (130) with object specific reflectance and luminescence spectral patterns, the object (130) is to be recognized,
- illuminating a scene including the object (130) with a light source (110) which is composed of at least two illuminants (111, 112, 113, 114, 115), by switching between the at least two illuminants (111, 112, 113, 114, 115), wherein at least one of the two illuminants is based on at least one solid-state system,
- measuring, by means of a sensor (120), radiance data of the scene including the object (130) when the scene is illuminated by the light source (110),
- providing a data storage unit (150) with luminescence spectral patterns together with appropriately assigned respective objects,
- estimating, by a data processing unit (140), the object specific luminescence spectral pattern of the object to be recognized out of the radiance data of the scene, and
- matching, by the data processing unit (140), the estimated object specific luminescence spectral pattern with luminescence spectral patterns stored in the data storage unit (150), and

- identifying, by the data processing unit (140), a best matching luminescence spectral pattern and, thus, its assigned object.

In another aspect, there is provided a computer program product having instructions that are executable by a computer, the computer program product comprising instructions:

- to provide an object (130) with object specific reflectance and luminescence spectral patterns, the object is to be recognized,
- to illuminate a scene including the object (130) with a light source (110) which is composed of at least two illuminants (111, 112, 113, 114, 115), by switching between the at least two illuminants, wherein at least one of the two illuminants is based on at least one solid-state system,
- to measure, by means of a sensor (120), radiance data of the scene including the object (130) when the scene is illuminated by the light source (110),
- to provide, by a data storage unit (150), luminescence spectral patterns together with appropriately assigned respective objects,
- to estimate, by a processing unit (140), the object specific luminescence spectral pattern of the object to be recognized out of the radiance data of the scene, and
- to match, by the processing unit (140), the estimated object specific luminescence spectral pattern with luminescence spectral patterns stored in the data storage unit (150), and
- to identify a best matching luminescence spectral pattern and, thus, its assigned object.

In the first exmple, the disclosure provides a system for object recognition via a computer vision application. The proposed system comprises at least the following components:

- an object to be recognized, the object having object-specific reflectance and luminescence spectral patterns,
- a light source which is composed of at least two illuminants and configured to give a specific spectral response on demand and to illuminate a scene including the object to be recognized by switching between the at least two

illuminants, wherein at least one of the at least two illuminants is based on at least one solid-state system,

- a sensor which is configured to measure radiance data of the scene including the object when the scene is illuminated by the light source,
- a data storage unit which stores and provides luminescence spectral patterns together with appropriately assigned respective objects,
- a data processing unit which is configured to extract/estimate the object-specific luminescence spectral pattern of the object to be recognized out of the radiance data of the scene and to compare/match the estimated/extracted object-specific luminescence spectral pattern with the luminescence spectral patterns stored in the data storage unit, and to identify a best matching luminescence spectral pattern and, thus, the object assigned to the identified best matching luminescence spectral pattern.

The at least one solid-state system may be chosen from the group of solid-state systems comprising semiconductor light-emitting diodes (LEDs), organic light-emitting diodes (OLEDs), or polymer light-emitting diodes (PLEDs).

In some examples, it may be advantageous to switch between the illuminants of the light source at a rate faster than the human eye can detect. It may be preferred to use fast switching LEDs with broad emission bands, or still more ideally, narrow bands.

By designing unique luminescence spectral patterns and forming a database of luminescence spectral patterns of objects/articles, it is possible to recognize an object displaying one of that luminescence spectral patterns using the proposed system. The proposed system allows to identify discrete luminescence spectral patterns in spectral dimension of an image which is taken by the sensor. It is to be stated that the number of spectral characters is independent of the shape of the object to be recognized. This enables the proposed system to not be limited in number of classifications to geometry/shape of objects. Objects with the

same shape and even the same color can be distinguished by analyzing the chemical (luminescence) information extracted by the data processing unit.

According to a possible example of the system, the system further comprises a display unit which is configured to display at least the identified object which is assigned to the identified best matching luminescence spectral pattern.

According to a further example, the object to be recognized, is imparted, e. g. coated, with predefined surface luminescent materials (particularly luminescent dyes) whose luminescent chemistry, i.e. luminescence spectral pattern, is known and used as a tag. By using luminescent chemistry of the object as a tag, object recognition is possible irrespective of the shape of the object or partial occlusions.

Luminescence is the property of light being emitted from a material without heat. A variety of luminescence mechanisms, such as chemiluminescence, mechanoluminescence, and electroluminescence are known. Photoluminescence is the emission of light/photons due to the absorption of other photons. Photoluminescence includes fluorescence, phosphorescence, upconversion, and Raman scattering. Photoluminescence, fluorescence and phosphorescence are able to change the color appearance of an object under ordinary light conditions. While there is a difference between the chemical mechanisms and time scales of fluorescence and phosphorescence, for most computer vision systems they will appear identical. Within the scope of the present disclosure the terms "fluorescence" and "fluorescent" are mostly used (exemplarily and as placeholder), however, a variety of luminescent mechanisms are applicable to the disclosure.

The object can be imparted, i. e. provided with fluorescent materials in a variety of methods. Fluorescent materials may be dispersed in a coating that may be applied through methods such as spray coating, dip coating, coil coating, roll-to-

roll coating, and others. The fluorescent material may be printed onto the object. The fluorescent material may be dispersed into the object and extruded, molded, or cast. Some materials and objects are naturally fluorescent and may be recognized with the proposed system and/or method. Some biological materials (vegetables, fruits, bacteria, tissue, proteins, etc.) may be genetically engineered to be fluorescent. Some objects may be made fluroescent by the addition of fluorescent proteins in any of the ways mentioned herein.

A vast array of fluorescent materials is commercially available. Theoretically, any fluorescent material should be suitable for the computer vision application, as the fluorescent spectral pattern of the object to be identified is measured after production. The main limitations are durability of the fluorescent materials and compatibility with the host material (of the object to be recognized). One example of suitable fluorescent materials are the BASF Lumogen® F series of dyes, such as, for example, yellow 170, orange 240, pink 285, red 305, a combination of yellow 170 and orange 240 or any other combination thereof. Another example of suitable fluorescent materials are Clariant Hostasol® fluorescent dyes Red GG, Red 5B, and Yellow 3G. Optical brighteners are a class of fluorescent materials that are often included in object formulations to reduce the yellow color of many organic polymers. They function by fluorescing invisible ultraviolet light into visible blue light, thus making the produced object appear whiter. Many optical brighteners are commercially available, including BASF Tinopal® SFP and Tinopal® NFW and Clariant Telalux® KSI and Telalux® OB1.

According to still a further example of the proposed system, the data processing unit is configured to identify the best matching fluorescence spectral pattern by using any number of matching algorithms between the extracted/estimated object-specific fluorescence spectral pattern and the stored fluorescence spectral patterns, the matching algorithms being chosen from the group comprising but not limited to: lowest root mean squared error, lowest

mean absolute error, highest coefficient of determination, matching of maximum wavelength value.

The processing unit is further configured to estimate/calculate, using the measured radiance data under the at least two illuminants, the fluorescence spectral pattern of the object and, afterwards, to match the estimated/calculated fluorescence spectral pattern to the known database of a plurality of fluorescence spectral patterns. According to an example of the claimed system, the processing unit is configured to estimate, using the measured radiance data under the at least two illuminants, the luminescence spectral pattern and the reflective spectral pattern of the object in a multistep optimization process.

The sensor is generally an optical sensor with photon counting capabilities. More specifically, it may a monochrome camera, or an RGB camera, or a multispectral camera, or a hyperspectral camera. The sensor may be a combination of any of the above, or the combination of any of the above with a tuneable or selectable filter set, such as, for example, a monochrome sensor with specific filters. The sensor may measure a single pixel of the scene, or measure many pixels at once. The optical sensor may be configured to count photons in a specific range of spectrum, particularly in more than three bands. It may be a camera with multiple pixels for a large field of view, particularly simultaneously reading all bands or different bands at different times.

A multispectral camera captures image data within specific wavelength ranges across the electromagnetic spectrum. The wavelengths may be separated by filters or by the use of instruments that are sensitive to particular wavelengths, including light from frequencies beyond the visible light range, i.e. infrared and ultra-violet. Spectral imaging can allow extraction of additional information the human eye fails to capture with its receptors for red, green and blue. A multispectral camera measures light in a small number (typically 3 to 15) of

sources connected to the network can be synced to have the same temporal and spectral change frequencies amplifying the effect.

In another example, the disclosure is directed to a method for object recognition via a computer vision application. The proposed method comprises at least the following method steps:

- providing an object with object specific reflectance and fluorescence spectral patterns, the object is to be recognized,
- illuminating a scene including the object with a light source which is composed of at least two illuminants by switching between the at least two illuminants, wherein at least one of the at least two illuminants is based on at least one solid-state system,
- measuring, by means of a sensor, radiance data of the scene including the object to be recognized when the scene is illuminated by the light source,
- providing a data storage unit such as a database with fluorescence spectral patterns linked with appropriately assigned respective objects,
- estimating, by a data processing unit, the object-specific fluorescence spectral pattern of the object to be recognized out of the radiance data of the scene, and
- comparing/matching, by the data processing unit, the estimated object-specific fluorescence spectral pattern of the object to be recognized with the fluorescence spectral patterns stored in the data storage unit, and
- identifying, by the data processing unit, a best matching fluorescence spectral pattern and, thus, the object assigned to the best matching fluorescence spectral pattern.

The step of providing an object with an object specific reflectance and fluorescence spectral pattern comprises, according to a possible example, in the case of an artificial object, for example, imparting fluorescence to the object to be recognized with a fluorescence material.

In the case of a natural object as the object to be recognized, it is possible that the object intrinsically already has object specific reflectance and fluorescence spectral patterns.

The step of imparting fluorescence to the object may be realized by coating the object with the fluorescence material or otherwise imparting fluorescence to the surface of the object. In the latter case fluorescence may be distributed throughout the whole object, and may thus be detectable at the surface as well.

According to a possible example of the proposed method, the method further comprises the step of displaying via a display device at least the identified object which is assigned to the identified best matching fluorescence spectral pattern.

The matching step of the proposed method particularly comprises to identify the best matching fluorescence spectral pattern by using any number of matching algorithms between the estimated object-specific fluorescence spectral pattern and the stored fluorescence spectral patterns, the matching algorithms being chosen from the group comprising but not limited to lowest root mean squared error, lowest mean absolute error, highest coefficient of determination, matching of maximum wavelength value. Generally, the matching algorithms are arbitrary.

The estimating step of the proposed method particularly comprises to estimate, using the measured radiance data under the at least two illuminants, the fluorescent spectra and the reflective spectra of the object.

The step of providing the data storage unit comprises to form a database of fluorescence chemistry information of objects, i.e. of fluorescence spectral patterns of objects/articles by designing multiple fluorescent formulations, each fluorescent formulation being applied and, thus, assigned to an object such that the object obtains and displays an object-specific fluorescence spectral pattern

when being illuminated by the light source. This can be achieved by using specific mixtures of fluorescent chemicals with different emission profiles in specific ratios to achieve different unique spectral signatures/fluorescence spectral patterns.

Particularly, the light source is chosen as a switchable light source with two illuminants and with a short switchover time between the two illuminants, i.e. the two illuminants change rapidly among one another. It is further possible that the two illuminants are two sinusoidal-like illuminants of opposite phases. The two illuminants can be chosen as LED illuminants.

The step of capturing the radiance data of the scene is particularly performed by a sensor which is linked and synchronized to the switching of the light source between the at least two illuminants. It is possible to only capture information during the time period one illuminant is active. Alternatively, it is also possible to capture information during the time period one or more illuminants are active and to use various algorithms to calculate the radiance for a subset of the illuminants.

In another example, the disclosure provides a computer program product having instructions that are executable by a computer, the computer program product comprising instructions to realize/perform/execute any one of the examples of the proposed method.

The present disclosure refers to a system and a method where fluorescence spectra of an object to be recognized are characterized under controlled and temporal lighting conditions and at spectral bands/lines of interest while the spectral signature of the fluorescent formulation, which is applied to the object to be recognized, is used for object recognition in computer vision applications. The proposed system and method enable recognition of an object irrespective of its shape, ambient lighting, and partial occlusions by using fluorescence

One of the key examples of the disclosure is that ambient lighting elements can be utilized as light probes for the proposed system and method. Indoor conditions usually require a controlled and uniform lighting environment to be present to facilitate computer vision applications. However, the proposed system and method capitalize on the differences of lighting conditions to recognize objects instead. Furthermore, one unique example of the system is that it utilizes a rapid change of ambient lighting from a LED light source or comparable arrangements to extract fluorescence chemistry information from a respective object. The rapid changing of such lighting conditions is not visible to human eyes and the spectral changes of lighting sources can be managed by the system through a network, working in sync with the sensor's integration times. Multiple light sources connected to the network can be synced to have the same temporal and spectral change frequencies amplifying the effect.

Another unique example of the disclosure is that the fluorescence (or chemistry) information of the objects can be coupled to information about that object, i.e. type of material, price, manuals, etc. and information held at the dynamic (live) database, i.e. the data storage unit that tracks and updates the information in 3D maps. By dynamically tracking the objects in 3D space using the proposed system and potentially in combination with other methods, the proposed system would enable the ability to distinguish two identical objects by 3D location of those objects for as long as the object locations are dynamically updated, and the objects are in field of view of the sensor of the proposed system.

The above-mentioned examples highlighting the unique utility of the proposed system are not complete and it is not intended to be limited to those specific applications. Further applications can be based on platforms using cameras of various types, including monochrome, RGB type, multispectral or hyperspectral sensors of light.

According to one example of the proposed method the object to be recognized is provided with a luminescence material which is chosen from the group comprising at least:

Any material with fluorescence (Stokes) characteristics in the UV, VIS, NIR and/or IR, any material with upconversion (anti-Stokes) characteristics in VIS and/or NIR, biologicals designed with fluorescence effects, biologicals designed with natural fluorescence effects, and/or food colorants.

The technique for imparting the object to be recognized with a luminescence material can be chosen as one or a combination of the following techniques: spraying, rolling, drawing down, deposition (PVC, CVD, etc.), extrusion, film application/adhesion, glass formation, molding techniques, printing such as inks, all types of gravure, inkjet, additive manufacturing, fabric/textile treatments (dye or printing processes), dye/pigment absorption, drawings (hand/other), imparting stickers, imparting labels, imparting tags, chemical surface grafting, dry imparting, wet imparting, providing mixtures into solids, providing reactive/nonreactive dyes.

The sensor to measure the radiance data of the scene can be chosen of the group comprising at least: photodiodes of all types, sensors covering wavelengths from 250 nm and above, sensors covering wavelengths up to 1.800 nm, sensors having dynamic or static filters, prism based or comparable spatially wavelength separated systems, multiple cameras, stereocameras, hyperspectral sensors (≥ 10 bands), multispectral sensors (> 3 bands), RGB sensors (3 bands), sensors covering all bands or only selected bands, sensors covering all frame rates, other sensors responsive to photons and/or electromagnetic radiation (250 nm to 1.800 nm), sensors comprising polarized filters (circular, linear, etc.), sensors having nonpolarized filters.

The database can be stored on an edge computing system or it can be stored on a cloud. The data can be stored with or without additional information

concerning the respective objects attached, ads, price, owner, SDS, calorie values, recipes. Further data can be provided with expiration date, date of manufacture, name, shelf life, ingredients list, location, time stamp of the respective objects. Further the data can be provided with use instructions, manufacturer, place of origin, recycling directions, manuals, ratings, reviews concerning the respective objects. Further the data can be provided with information about traffic signage information, data about type of material such as textile, clothing, dog leash, bicycle, car etc. concerning the respective objects. Further, it can be provided with data about usage levels, remaining amounts, weight, volume, alcohol content, alcohol consumed of the respective objects.

The identified object which is assigned to the best matching luminescence spectral pattern can be displayed via one or a combination of the following devices: smart glasses, smart phones, smart watches, other wearables such as chest cameras, spy cams, shoes, shirts, buttons, contact lenses, security cameras, vehicles, drones, robotics, home assistants, laptops, tablets, traffic monitor cameras, indoor and outdoor systems, mobile or stationary systems, TVs, toys, portable scanners, stationary scanners, coffee machines, home appliances, industrial machinery, production equipment/plants, recycling/sorting equipment, smart trash bins, smart recycling bins, pens.

The proposed method has many application areas. Thus, it can be used for example in: object recognition, object tracking, classification of objects, object identification, object locating, inventory management, automated orders, retail, online store, accident prevention autonomous vehicles, anti-counterfeiting, augmented reality or mixed reality applications, advertising, fitness/health management, warehousing, manufacturing, assembly, counting, learning, sports, instructions, manuals, advice, cooking, and artificial intelligence support.

The disclosure is further defined in the following examples. It should be understood that these examples, by indicating preferred examples of the

disclosure, are given by way of illustration only. From the above discussion and the examples, one skilled in the art can ascertain the essential characteristics of this disclosure and without departing from the spirit and scope thereof, can make various changes and modifications of the disclosure to adapt it to various uses and conditions.

Figure 1 shows schematically embodiments of the proposed system.

Figure 2 shows measured radiances of three broadband light sources used in example 1.

Figure 3 shows an example comparison of measured and calculated emission spectral patterns for one material from example 1.

Figure 4 shows measured (top) and calculated (bottom) emission spectra (spectral patterns) for all materials for example 1.

Figure 5 shows in different tables different comparing/matching algorithms for example 1.

Figure 6 shows a diagram of example illuminant spectrums and measured radiances under a LED light source used in an embodiment of the proposed system.

Figure 7 shows a diagram of an example comparison of measured and calculated emission spectra (spectral patterns).

Figure 8 shows calculated emission spectra (spectral patterns) (left) and measured emission spectra (spectral patterns) (right).

Figure 9 shows in different tables different comparing/matching algorithms which can be used for example 2.