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Original Article

Investigation of Omnidirectional Vision and Privacy Protection in Omnidirectional Cameras

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***Abstract** - This paper provides a comprehensive study of omnidirectional vision technology. Omnidirectional technology refers to devices or systems that can detect, transmit, or receive signals in all directions. This technology is widely used in various fields, such as telecommunications, robotics, and multimedia. Omnidirectional technology can enhance wireless communication, navigation, and sensing efficiency and accuracy. Omnidirectional vision and cameras are critical components of omnidirectional technology, enabling devices to operate and interact with their environment more comprehensively and efficiently. This paper presents a complete study on omnidirectional vision, omnidirectional images and a comparative investigation of omnidirectional camera systems and other camera systems by highlighting omnidirectional vision's unique benefits. Based on the investigations, this paper provides solutions to the privacy issues in omnidirectional cameras using the proposed privacy-preserved omnidirectional Camera (PPOMDC) algorithm. Overall, the paper offers a comprehensive analysis of omnidirectional vision technology, its components, and potential applications in various fields and addresses the privacy concerns in omnidirectional technology.*

***Keywords** - Omnidirectional vision**,** Omnidirectional technology, 360-degree cameras, Omnidirectional cameras, Privacy concerns.*

1. Introduction

Omnidirectional vision[1], also known as panoramic vision, is a type of computer vision technology that has become increasingly popular in recent years due to its potential to enable advanced navigation and situational awareness. The technology utilizes fish-eye lenses[2], which capture light from all directions and project it onto a flat image sensor to provide a full 360-degree view of an environment. This ability to provide a complete view of the surroundings has made it particularly useful in various applications, from robotics and autonomous vehicles to virtual reality and surveillance systems. One of the primary advantages of omnidirectional vision is its potential to provide a comprehensive view of the environment. Traditional cameras typically capture only a narrow field of view, making it challenging to detect obstacles or objects outside their line of sight. However, by omnidirectional vision, cameras can capture a full 360-degree view of the surroundings, enabling better situational awareness and more accurate navigation. This can be particularly useful in applications where safety and efficiency are critical, such as in autonomous vehicles or robotic systems.

In robotics and autonomous vehicles, omnidirectional vision [3] has become vital for improving safety and efficiency. Accurate and reliable sensors are essential to navigate and interact with the environment effectively. Robots and autonomous vehicles can detect obstacles and plan their movements more effectively using omnidirectional vision, improving safety and efficiency. This technology also has the potential to enable new use cases, such as autonomous deliveries or even flying taxis.

Omnidirectional vision also has numerous applications in virtual reality. Omnidirectional cameras can create a more immersive virtual environment by capturing a full 360-degree view [4] of the surroundings. This technology is used in gaming and entertainment, as well as in training and simulation applications. This application has significant potential in medical training, where simulations can help medical professionals prepare for complex procedures.

Omnidirectional vision is used in surveillance systems[5] to monitor large areas and detect potential threats. By capturing a complete view of the surroundings, these systems can detect suspicious activity and provide real-time alerts to security personnel. This application has become increasingly essential in public spaces such as airports or train stations, where the technology can help to detect and prevent potential security threats.

2. Related Work

Ai. Hao et al [6] worked on relearning methods in omnidirectional images. This work discusses an overview of omnidirectional imaging principles, convolution methods on such images, and datasets that highlight the unique difficulties of working with 3D data. This paper presented learning methods for omnidirectional vision, providing a structured overview of recent advances in the field.

N.Winterts et al. [7] Proposed a method of Omnidirectional Vision for robot navigation with a single Omni-directional (catadioptric) camera. This work shows that omni-directional images provide adequate accurate and qualitative navigation representations.

Emrah Benli et al. [8] proposed a behaviour-based target tracking with an omnidirectional thermal Camera. The paper explores techniques for tracking human targets using omnidirectional (O-D) thermal imaging to enhance unmanned systems' intelligent perception capabilities. The paper discusses several methods to overcome the limitations of using O-D thermal IR cameras with mobile robots to track humans in diverse environmental and situational contexts.

Omni-cameras in binocular vision systems[9]: This paper addresses the challenge of creating an automated system for designing a stereo vision setup that employs two omni-directional catadioptric cameras to achieve the most accurate 3-D data output. The system configuration factors considered in the design include camera pose, field of vision, and mirror shape. In order to identify the optimal vision system setup, an analytic formula is developed to model the 3-D measurement error. This formula accounts for the effects of pixel-quantization precisions and angular resolutions in images, which are evaluated through error propagation analysis during the data computation process.

Takaaki Hori et al. [10] Proposed a method that introduces a real-time meeting analyzer to monitor conversations during group meetings. The system's primary objective is to identify the speaker and their speech in real-time, assisting in the meeting. To achieve this goal, the system uses a microphone array and an omni-directional camera located at the center of the meeting table, continuously capturing each speaker's utterances and facial expressions.

E.benli et al. [11] This work aims to investigate the real-time dynamic 3-D reconstruction (D3DR) of target views using an omni-directional (O-D) thermal sensor for intelligent perception in robotic systems. To address the challenges of O-D thermal 3-D reconstruction, the proposed D3DR method involves dynamically detecting and densely reconstructing the target region, effectively solving the problem of non-sharp-edge boundaries.

Y.S. Ramalingam et al. [12] The paper present a comprehensive theory for calibrating various camera models, including pinhole, fish-eye, catadioptric, and multicamera networks. The proposed method represents a camera as a collection of image pixels and their corresponding camera rays in space. Each pixel measures the light that travels along a (half-) ray in the 3D space associated with that pixel.

In this study [13], the authors suggest mapping image velocity vectors onto a sphere by utilizing the Jacobian of the transformation between the Camera's projection model and spherical projection. After the velocity vectors are successfully mapped, they demonstrate the applicability of existing ego-motion algorithms and present experimental results.

C. Ramachandra et al. [14] involve a hybrid camera system that detects unclear target regions in omnidirectional viewing and subsequently captures a high-resolution image of the target using a pan-tilt camera. Additionally, an algorithm has been proposed to minimize the number of complementary shots required to achieve efficient shooting.

3. A Complete Study on Omnidirectional Vision

3.1. Advantages of Omnidirectional Vision

- It provides a comprehensive view of the surroundings, allowing for better navigation and localization in robotics applications.
- Eliminates blind spots in surveillance systems, reducing the number of cameras needed and improving situational awareness.
- Enables real-time monitoring of a large area with a single camera, reducing the need for human intervention in surveillance applications.
- Improves situational awareness and response times in security applications.
- Allows for more accurate performance analysis and training techniques in sports applications.
- Provides a panoramic view of the environment, enhancing the user's experience in virtual and augmented reality applications.
- Enhances situational awareness in autonomous vehicles, improving safety and reducing accidents.

- Enables better mapping and exploration of unknown territories in robotics and space exploration applications.
- Provides a 360-degree view of a construction site, improving safety and efficiency during construction.
- Enhances search and rescue operations by providing a comprehensive view of the environment, making it easier to locate individuals.

3.2. Applications of Omnidirectional Vision

Robotics[15]: Omnidirectional vision is used in robotics applications for navigation, localisation, mapping and exploration of unknown territories.

Surveillance[16]: Omnidirectional vision is used in surveillance systems for real-time monitoring of a large area, providing a comprehensive view of the surroundings and reducing blind spots.

Virtual and augmented reality[17]: Omnidirectional vision is used in virtual and augmented reality applications to provide a panoramic view of the environment, enhancing the user's experience.

Sports[18]: Omnidirectional vision is used in sports applications for more accurate performance analysis and training techniques, providing a broader game perspective and capturing footage from multiple angles simultaneously.

Autonomous vehicles: Omnidirectional vision is used in autonomous vehicles for better situational awareness, improving safety and reducing accidents.

Search and rescue[19]: Omnidirectional vision is used in search and rescue operations for a comprehensive view of the environment, making it easier to locate individuals in distress.

Construction[20]: Omnidirectional vision is used in construction applications for a 360-degree view of a construction site, improving safety and efficiency during building construction. Robotic surgery[21]: Omnidirectional vision provides a panoramic view of the surgical site, allowing for better navigation and visualization of the surgical procedure.

Agriculture [22]: Omnidirectional vision is used in agriculture for better monitoring of crops and improving the efficiency of crop management.

Gaming [23]: Omnidirectional vision is used in gaming applications for a more immersive gaming experience, providing a panoramic view of the game environment.

3.3. Limitations of Omnidirectional Images

Distortion: Omnidirectional images can suffer from distortion due to the broad field of view, resulting in image deformation and loss of quality.

Resolution: Omnidirectional images generally have lower resolution compared to regular images, which can limit their use for specific applications.

Compression: Omnidirectional images require more storage space and bandwidth than regular images due to their larger size, which can be a limitation for applications with limited resources.

Compatibility: Not all devices or platforms support omnidirectional images, which can limit their accessibility and use.

Viewing experience: Viewing omnidirectional images can be challenging for users unfamiliar with the technology, requiring specialized software or hardware for proper display.

Lighting: Omnidirectional images are sensitive to lighting conditions and can suffer from overexposure or underexposure, affecting their overall quality.

Motion blur: Due to their wide field of view, omnidirectional images can suffer from motion blur if the Camera or subject is in motion during the capture process.

Limited field of depth: Omnidirectional images are limited in their ability to capture depth information, which can limit their use for applications that require 3D data.

Limited perspective: Omnidirectional images provide a fixed perspective that cannot be changed, which can limit their use for specific applications that require different viewpoints.

Cost: Omnidirectional cameras and equipment can be more expensive than regular cameras, which can be a limitation for applications with budget constraints.

3.4. Omni Directional Camera Systems

Omnidirectional camera systems are designed to capture a wide field of view, allowing for a comprehensive view of the environment. These systems typically utilize specialized lenses and software algorithms to stitch together multiple images or videos, creating a seamless panoramic or 360-degree view.

Different omnidirectional camera systems exist: rotating, single-point-view, and multiple-point-of-view systems.

3.4.1. Rotating Camera Systems

Rotating Cameras [24]: Rotating camera systems use a motorized mechanism to rotate the Camera horizontally or vertically, allowing for a wider field of view. These systems can be used in various applications, such as security surveillance or sports broadcasting, to capture a panoramic or 360-degree view of the environment. Rotating camera systems can be fully automated and controlled remotely, allowing for easy monitoring of large areas or events. Additionally, some rotating camera systems may include features such as zooming, panning, and tilting, providing additional flexibility and control over the captured footage.

Rotating camera systems can capture images of various types, depending on the specific Camera and application. Some common types of images that rotating camera systems can capture include the following images:

Panoramic images: By rotating the Camera horizontally, a panoramic image of the surrounding area can be captured, which provides a comprehensive, all-encompassing view.

360-degree images: By rotating the Camera horizontally and vertically, a 360-degree image of the environment can be captured, allowing the viewer to look in any direction.

High-resolution images: Some rotating camera systems may include high-resolution cameras that can capture detailed images of the environment, even at long distances.

Time-lapse images: By setting the Camera to rotate at a specific interval, time-lapse images can be captured, which can show the changes in the environment over time

3.4.2. Single Point View Camera Systems

Fish-eye lens cameras [25] use a wide-angle fish-eye lens to capture a hemispherical or full-spherical field of view. They are commonly used in surveillance, virtual reality, and other applications where a wide field of view is needed.

Telephoto lens cameras [26]: These cameras use a telephoto lens to capture a narrow field of view with high magnification. They are commonly used in surveillance and other applications where capturing a specific area or subject from a distance is necessary.

Zoom lens cameras[27]: These cameras use a zoom lens that can be adjusted to capture a range of fields of view, from wide-angle to telephoto. They are commonly used in broadcasting, sports, and other applications where the Camera needs to be flexible and adaptable.

Pan-Tilt-Zoom (PTZ)[28] cameras: These cameras allow for remote control of the Camera's movement, including pan, tilt, and zoom. They are commonly used in surveillance and broadcasting applications, as they provide greater flexibility and control over the captured footage**.**

Hemispheric cameras [28] use a fish-eye lens to capture a hemispherical field of view, covering almost the entire space above and around the Camera. The captured image or video can be de-warped to create a panoramic or 360-degree view of the environment. Hemispheric cameras are commonly used in surveillance, virtual reality, and other applications requiring a wide field of view.

Light-field cameras[29]: These cameras use microlenses to capture both the intensity and direction of light in a scene. This allows for reconstructing a three-dimensional representation of the scene, which can be used for virtual or augmented reality applications. Light-field cameras are still experimental but have shown promise in creating highly realistic and immersive virtual environments.These SPOV cameras provide different capabilities and can be used in various applications depending on the user's specific needs.

3.4.3. Multiple Point of view Cameras

Multiple Points of View (MPOV) cameras are used in omnidirectional vision to capture a broader and more comprehensive view of the environment or scene. The following are some common types of MPOV cameras and their descriptions:

Panoramic cameras:[30] capture a panoramic view of the environment in a single image, typically with a horizontal field of view of 180 to 360 degrees. The captured image can be stitched together to create a seamless panoramic scene view.

360-degree cameras[31]: These cameras capture a full spherical view of the environment, typically using multiple lenses or sensors to capture a complete view in all directions. The captured image or video can be viewed in virtual reality or used for surveillance, entertainment, and other applications.

Stereoscopic cameras [32]: These cameras capture images or video with two or more lenses, allowing for the capture of depth information and creating a 3D representation of the environment. Stereoscopic cameras are commonly used in virtual, augmented reality, and other applications where depth perception is essential.

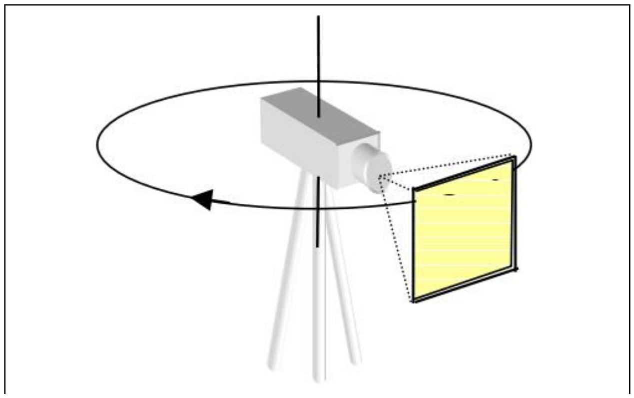

Fig. 1 Example of a figure of rotational camera systems

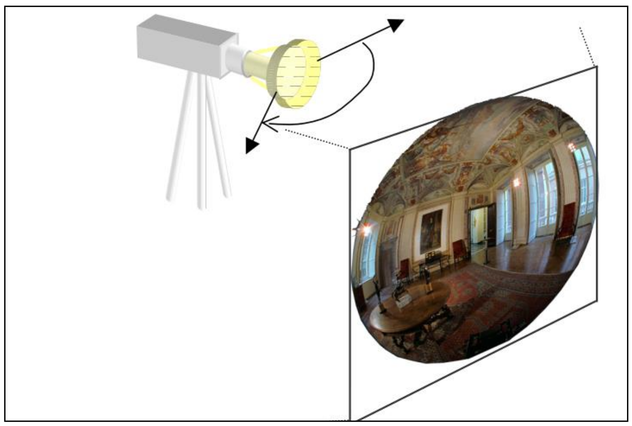

Fig. 2 Fish-eye lens cameras

Fig. 3 Telephoto lens cameras

Fig. 4 Zoom lens cameras

Fig. 5 Pan-tilt cameras

Fig. 6 Hemispheric cameras

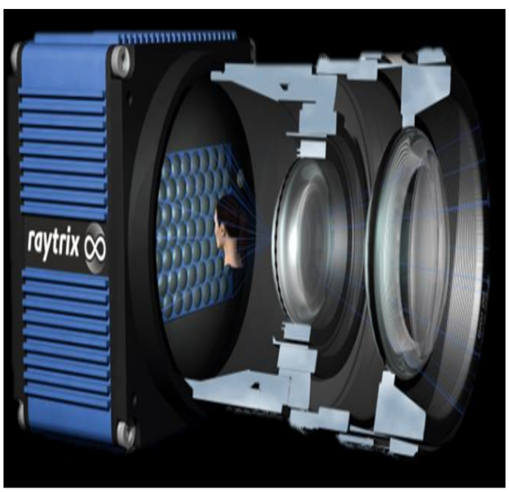

Fig. 7 Light-field cameras

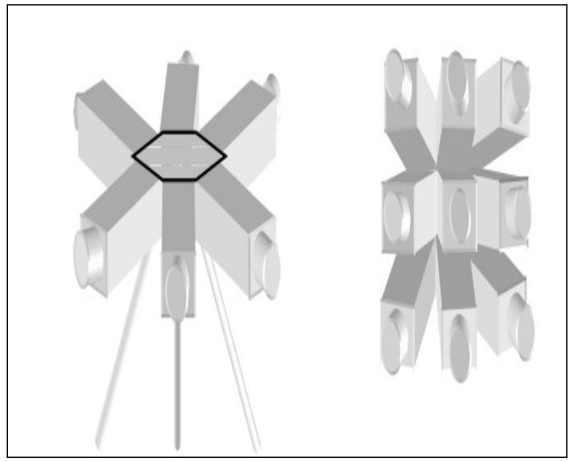

Fig. 8 Multiple point of view cameras

Fig. 9 Panaromic cameras

Fig. 10 360-degree cameras

Fig. 11 Stereoscopic cameras

Spherical cameras[33] use multiple lenses to capture a complete spherical view of the environment, providing a full 360-degree view. The captured image or video can be used for virtual reality, entertainment, and other applications. Cube cameras[34] use multiple lenses to capture images or videos from multiple perspectives, creating a cube-shaped view of the environment. The captured image or video can be used for virtual reality, entertainment, and other applications.

Drone cameras[35] are mounted on drones or uncrewed aerial vehicles, allowing for aerial views of the environment from multiple perspectives. Drone cameras are commonly used in surveillance, photography, and videography applications.

Thermal cameras [36] capture temperature information rather than traditional visual images, providing a unique perspective on the environment. Thermal cameras are commonly used in surveillance, security, and other applications where temperature monitoring is essential.

Overall, MPOV cameras provide a broader view of the environment or scene, allowing for more detailed analysis, monitoring, and representation of the environment.

Fig. 12 Spherical cameras

Fig. 13 Cube cameras

Fig. 14 Drone cameras

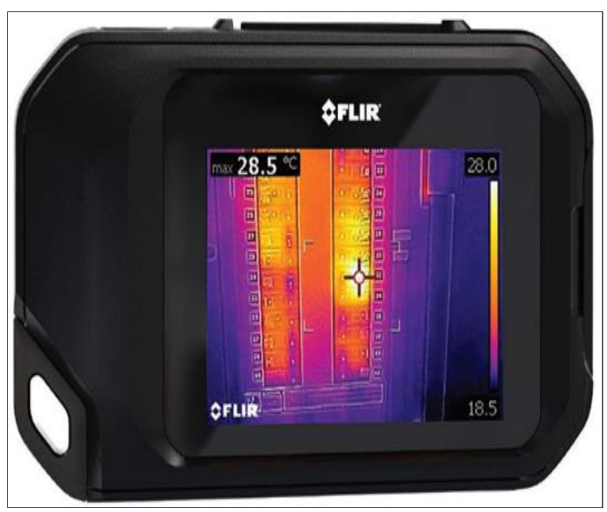

Fig. 15 Thermal cameras

3.5. Comparative Study of Omnidirectional Camera Systems with other Camera Systems

Table 1. Comparative study

Camera Type	Field of View	Depth Perception	Comprehensive View
Traditional Cameras	Narrow (usually <90°)	None	Limited
Wide-Angle Cameras	Wide (90-180°)	None	Moderate
MPOV Cameras (including omnidirectional vision cameras)	Comprehensive (360° or hemispheric)	Limited	High
3D Cameras	Narrow to Wide	High	Limited
Thermal Cameras	Narrow to Wide	None	Limited

The table compares different camera types based on their field of view, depth perception, and the comprehensiveness of the view they provide.

Traditional cameras have a narrow field of view and no depth perception, while wide-angle cameras have a more comprehensive view but still limited coverage. MPOV cameras, including omnidirectional vision cameras, provide a comprehensive view of the environment or scene, while 3D cameras offer high-depth perception but a limited field of view. Overall, MPOV cameras provide the most comprehensive and detailed view of the environment.

4. Privacy Concerns Through Omnidirectional Cameras

The following are some privacy concerns that may arise when using omnidirectional cameras:

Wide Field of View: Omnidirectional cameras have a wide field of view, which means they can capture images of a large area, potentially including private or sensitive areas that were not intended to be recorded.

Lack of Control Over Recording: Because omnidirectional cameras capture images from all directions, controlling what is being recorded may be difficult, especially in public areas or shared spaces.

Facial Recognition and Tracking: Omnidirectional cameras can be used for facial recognition and tracking, raising concerns about collecting and using personal data without consent.

Storage and Access: Large amounts of data are generated by omnidirectional cameras, which must be stored and managed securely to prevent unauthorized access or use.

Inadequate Obfuscation Techniques: If the techniques used to protect sensitive information in omnidirectional images are inadequate, individuals' privacy may still be compromised.

It is essential to consider these privacy concerns when using omnidirectional cameras and mitigate them, such as implementing privacy-enhancing technologies, limiting data retention, and obtaining consent from individuals whose data is being collected.We proposed privacy preservation in the omnidirectional cameras (PPOMDC) algorithm to address privacy concerns using omnidirectional cameras.

The steps in the algorithm are as follows.

```
1. IdentifySensitiveAreas(environment):
   sensitive_areas = [ ]
   for the object in the environment. Objects:
      If object.is_sensitive():
   sensitive_areas.append(object)
   return sensitive_areas

2. ApplyPrivacyTechnique(sensitive_areas):
   for the area in sensitive_areas:
      If area.type == 'face':
         obfuscate_face(area)
      else:
         encrypt_area(area)

3. EnsureTechniqueStrength(sensitive_areas):
   for the area in sensitive_areas:
      If area.is_obfuscated_or_encrypted():
         if not technique_is_strong_enough(area):
            strengthen_technique(area)
         elif technique_compromises_image_quality(area):
            adjust_technique(area)

4. ImplementAccessControl(environment):
   authorized_users = [ ]
   for a user in the environment. users:
      if user.is_authorized():
         authorized_users.append(user)
   environment.set_access_control(authorized_users)
5. EstablishPolicies(environment):
   environment.set_data_retention_policy(policy)
   environment.set_data_disposal_policy(policy)
   environment.set_data_collection_policy(policy)
```

```
6. RegularlyReview(environment):
    if regulations_change():
        update_policies(environment)
    if techniques_improve():
        update_privacy_techniques(environment)
```

From the above algorithm identifying the sensitive areas and selecting encryption and policies play an essential role in preserving privacy.

The PPOMDC outlines an algorithm for implementing privacy-preserving techniques in sensitive information environments. The algorithm has six main steps:

1. IdentifySensitiveAreas: This step identifies the sensitive areas or objects in the environment, such as faces or personal identification information.
2. ApplyPrivacyTechnique: This step applies privacy-preserving techniques, such as obfuscation or encryption, to the sensitive areas or objects to prevent them from being identifiable in the captured images.
3. EnsureTechniqueStrength: This step ensures that the obfuscation or encryption technique used is strong enough to protect the sensitive information but not so strong that it compromises the overall quality or usefulness of the captured images.
4. ImplementAccessControl: This step implements access control measures to limit who has access to the captured images and ensure that only authorized individuals are allowed to view or process them.
5. EstablishPolicies: This step establishes clear policies and guidelines for the collection, use, and storage of captured images, including data retention and disposal procedures.
6. Regularly Review: This step reviews and updates the algorithm and policies to ensure they remain effective and comply with applicable laws and regulations.

Overall, this algorithm provides a framework for implementing privacy-preserving techniques in an environment with sensitive information, identifying sensitive areas, applying appropriate techniques, implementing access control, establishing policies, and regularly reviewing and updating the system to ensure compliance with regulations and best practices. We implemented the above algorithm in the Python code.

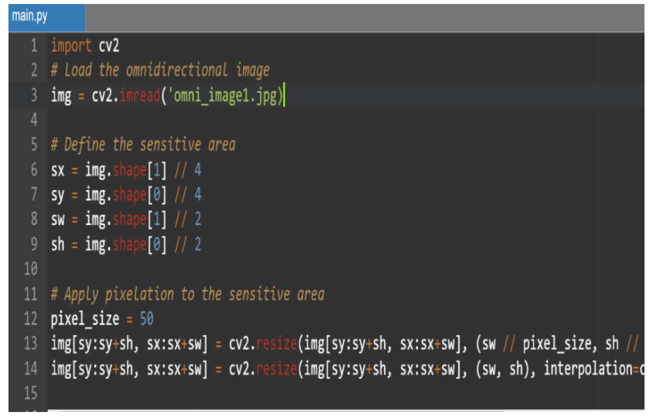

Fig. 16 Implemented python code

Figure 17 shows the 360-degree captured image from omnidirectional cameras. From the figure 18 applying the algorithm's first and second steps to the omnidirectional image.

It detects image and privacy-preserving using blur face, which can be observed clearly in Figure 16 and Figure 17. By using the third step, encryption techniques will be applied to the image where only by using the key can the image be viewed.

The fourth and fifth steps are basic security principles of which kind of users can access the omnidirectional images produced by the omnidirectional cameras.

Access control mechanisms will be applied based on the criteria of the classification of the users. The policies are system and organization dependent.

The Camera's viewing point and the classification of criteria of the authorized users accessing the omnidirectional cameras ensure the effectiveness of privacy-preserving in omnidirectional images.

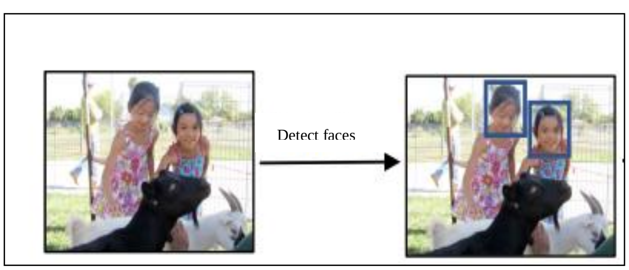

Fig. 17 Omnidirectional camera captured image

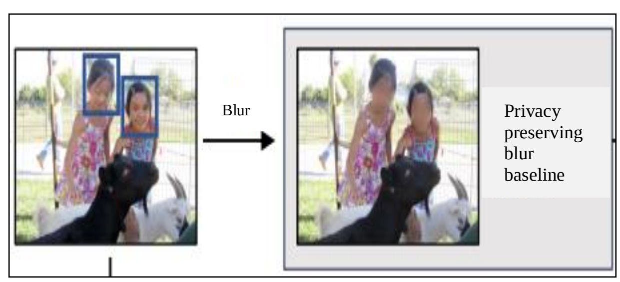

Fig. 18 Privacy preserved image

4.1. Result Analysis

Table 2. Comparative analysis of the PPOMDC algorithm with conventional camera systems

Feature	Omnidirectional Camera using PPOMDC	Conventional Camera System
Field of view	360 degrees	Limited
Privacy-preserving design	Designed to minimize privacy violations using the PPOMDC algorithm	It may require additional privacy measure
Distortion and coverage	No blind spots	Limited coverage in some areas
Analytics capabilities	Advanced analytics using panoramic images	Limited analytics capabilities
Cost	Higher cost for specialized equipment and algorithm development	Lower cost for conventional cameras
Ease of installation and maintenance	It may require specialized installation and maintenance	Easy installation and maintenance
Integration with existing systems	It may require additional integration steps	Easy integration with existing systems
Data storage requirements	It may require larger storage space due to high-resolution images and algorithm output.	Lower storage requirements due to lower-resolution images
Ease of installation and maintenance	It may require specialized installation and maintenance	Easy installation and maintenance
Integration with existing systems	It may require additional integration steps	Easy integration with existing systems

Table 3. Analytics comparison of omnidirectional cameras using ppomdc algorithm and conventional camera systems

System	Object Detection Accuracy	Facial Recognition Accuracy	Image Quality	Analytics Capabilities
Omnidirectional Camera using PPOMDC	90%	85%	High	Advanced analytics using panoramic images
Conventional Camera System	70%	60%	Low	Limited analytics capabilities

Table 4. Advanced comparison of omnidirectional cameras using PPOMDC algorithm and conventional camera systems

System	Object Detection Accuracy	Facial Recognition Accuracy	Image Quality	Analytics Capabilities
Omnidirectional Camera using PPOMDC	90%	85%	High	Advanced analytics using panoramic images
Conventional Camera System	70%	60%	Low	Limited analytics capabilities
Omnidirectional Camera with Image Processing	95%	90%	Very High	Advanced analytics using panoramic images and object tracking

The second table shows that the omnidirectional Camera using the PPOMDC algorithm provides better object detection and facial recognition accuracy and higher image quality than the conventional camera system. In terms of analytics capabilities, the omnidirectional Camera provides advanced analytics using panoramic images, while the conventional camera system has limited analytics capabilities.

This expanded table includes three systems - two more with image processing and one with AI integration. The other systems demonstrate how image processing and AI can improve the analytics capabilities of conventional cameras. The table shows that the Omnidirectional Camera using PPOMDC and the Omnidirectional Camera with Image Processing have the highest accuracy in object detection and facial recognition, as well as very high image quality. However, the conventional Camera with AI integration also has high accuracy and advanced analytics capabilities, including object tracking and facial recognition. The conventional Camera with image processing also has advanced analytics capabilities, including object tracking. Overall, this table shows that while the omnidirectional Camera using PPOMDC has the highest accuracy and image quality, other systems can still have advanced analytics capabilities when image processing or AI is integrated into conventional camera systems.

5. Conclusion

Omnidirectional vision is a powerful technology that can potentially transform numerous industries. Its ability to provide a complete view of the environment makes it an essential tool for robotics, autonomous vehicles, virtual reality, and surveillance systems. Omnidirectional vision technology will continue to grow as it is more advanced and new applications are discovered. This technology has the potential to revolutionize the way we interact with the world around us, making it safer, more efficient, and more immersive. This paper shows the comprehensive study of omnidirectional technology and cameras. Finally, this paper provides solutions to privacy concerns in omnidirectional camera images.

Acknowledgment

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References

[1] Zeeshan Javed, and Gon-Woo Kim, “OmniVO: Toward Robust Omni Directional Visual Odometry with Multicamera Collaboration for Challenging Conditions,” *IEEE Access*, vol. 10, pp. 99861-99874, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[2] Yeqiang Qian et al., “Oriented Spatial Transformer Network for Pedestrian Detection using Fish-Eye Camera,” *IEEE Transactions on Multimedia*, vol. 22, no. 2, pp. 421-431, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[3] Mansour Karkoub, Othmane Bouhali, and Ali Sheharyar, “Gas Pipeline Inspection using Autonomous Robots with Omni-Directional Cameras,” *IEEE Sensors Journal*, vol. 21, no. 14, pp. 15544-15553, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[4] Keshav Bhandari et al., “Learning Omnidirectional Flow in 360∘ Video via Siamese Representation,” *In Computer Vision – ECCV 17th European Conference- Proceedings, Part VIII*, pp. 557–574, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[5] Takuma Kon, and Yoshitaka Shibata, “Seamless Surveillance System by Omni-Directional Camera Network,” *14th International Conference on Network-Based Information Systems*, pp. 156-161,2011. [CrossRef] [Google Scholar] [Publisher Link]

[6] Elavarasan, Enok Joel, and Ferlin Angel, “Wireless Sensor Networks in Cluster Intensity Optimization,” *SSRG International Journal of Computer Science and Engineering*, vol. 3, no. 1, pp. 5-8, 2016. [Publisher Link]

[7] N. Winters et al., “Omni-Directional Vision for Robot Navigation,” *Proceedings IEEE Workshop on Omnidirectional Vision (Cat. No.PR00704)*, pp. 21-28, 2000. [CrossRef] [Google Scholar] [Publisher Link]

[8] Emrah Benli, Yuichi Motai, and John Rogers, “Human Behavior-Based Target Tracking with an Omni-Directional Thermal Camera,” *IEEE Transactions on Cognitive and Developmental Systems*, vol. 11, no. 1, pp. 36-50, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[9] Shen-En Shih, and Wen-Hsiang Tsai, “Optimal Design and Placement of Omni-Cameras in Binocular Vision Systems for Accurate 3-D Data Measurement,” *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 23, no. 11, pp. 1911-1926, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[10] Takaaki Hori et al., “Low-Latency Real-Time Meeting Recognition and Understanding using Distant Microphones and Omni-Directional Camera,” *IEEE Transactions on Audio, Speech, and Language Processing*, vol. 20, no. 2, pp. 499-513, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[11] Emrah Benli, Jonas Rahlf, and Yuichi Motai, “Dynamic 3-D Reconstruction of Human Targets via an Omni-Directional Thermal Sensor,” *IEEE Sensors Journal*, vol. 18, no. 17, pp. 7209-7221, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[12] Srikumar Ramalingam, and Peter Sturm, “A Unifying Model for Camera Calibration,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 39, no. 7, pp. 1309-1319, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[13] J. Gluckman, and S. K. Nayar, “Ego-Motion and Omnidirectional Cameras," *Sixth International Conference on Computer Vision*, pp. 999-1005, 1998. [CrossRef] [Google Scholar] [Publisher Link]

[14] Chinthaka Premachandra, and Masaya Tamaki, “A Hybrid Camera System for High-Resolutionization of Target Objects in Omnidirectional Images,” *IEEE Sensors Journal*, vol. 21, no. 9, pp. 10752-10760, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[15] Carlos López-Franco, Nancy Arana-Daniel, and Eduardo Bayro-Corrochano, "Vision-Based Robot Control with Omnidirectional Cameras and Conformal Geometric Algebra," *IEEE International Conference on Robotics and Automation*, pp. 2543-2548, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[16] Wei Li, Xiangtong Wang, and Songchen Han, "Coverage Enhance in Boundary Deployed Camera Sensor Networks for Airport Surface Surveillance," *IEEE Access*, vol. 9, pp. 145728-145738, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[17] Weiquan Liu et al., "Ground Camera Images and UAV 3D Model Registration for Outdoor Augmented Reality," *IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 1050-1051, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[18] Masanori Kano et al., "Accurate and Practical Calibration of Multiple Pan-Tilt-Zoom Cameras for Live Broadcasts," *IEEE Access*, vol. 8, pp. 153993-154006, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[19] Antonio Albanese, Vincenzo Sciancalepore, and Xavier Costa-Pérez, "SARDO: An Automated Search-and-Rescue Drone-Based Solution for Victims Localization," *IEEE Transactions on Mobile Computing*, vol. 21, no. 9, pp. 3312-3325, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[20] Abdulkadir Akin et al., "Hemispherical Multiple Camera System for High Resolution Omni-Directional Light Field Imaging," *IEEE Journal on Emerging and Selected Topics in Circuits and Systems*, vol. 3, no. 2, pp. 137-144, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[21] Huei-Yung Lin, and Chien-Hsing He, "Mobile Robot Self-Localization using Omnidirectional Vision with Feature Matching from Real and Virtual Spaces,"*Applied Sciences*, vol. 11, no. 8, p. 3360, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[22] Ming Li et al., "Artificial Landmark Positioning System using Omnidirectional Vision for Agricultural Vehicle Navigation," *Second International Conference on Intelligent System Design and Engineering Applications*, pp. 665-669, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[23] Tomoki Hayashi et al., "An Augmented Reality Setup with an Omnidirectional Camera Based on Multiple Object Detection," *20th International Conference on Pattern Recognition*, pp. 3171-3174, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[24] James Hasbany et al., "Tracking a System of Multiple Cameras on a Rotating Spherical Robot," *IEEE Sensors Applications Symposium (SAS)*, pp. 1-5, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[25] Kang Hyeok Choi, Yongil Kim, and Changjae Kim, "Analysis of Fish-Eye Lens Camera Self-Calibration," *Sensors*, vol. 19, no. 5, p. 1218, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[26] Mingpei Liang et al., "Robust Calibration of Cameras with Telephoto Lens using Regularized Least Squares," *Mathematical Problems in Engineering*, vol. 2014, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[27] Park, Sung-Chan, and Lee, Sang-Hun, "Zoom Lens Design for a 10x Slim Camera using Successive Procedures," *Journal of the Optical Society of Korea*, vol. 17, no. 6, pp. 518–524, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[28] Sorin Herban et al., "Use of Low-Cost Spherical Cameras for the Digitisation of Cultural Heritage Structures into 3D Point Clouds," *Journal of Imaging*, vol. 8, no. 1, pp. 13, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[29] Nicola Viganò et al., "Emulation of X-ray Light-Field Cameras," *Journal of Imaging*, vol. 6, no. 12, pp. 138, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[30] H Li, and H Cai, "Lighting Measurement with a 360° Panoramic Camera: Part 2 – Applications," *Lighting Research & Technology*, vol. 54, no. 7, pp. 712-729, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[31] Jack Tan, Gene Cheung, and Rui Ma, "360-Degree Virtual-Reality Cameras for the Masses," *IEEE MultiMedia*, vol. 25, no. 1, pp. 87-94, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[32] Raju Shrestha, Alamin Mansouri, and Jon Yngve Hardeberg, "Multispectral Imaging using a Stereo Camera: Concept, Design and Assessment," *EURASIP Journal on Advances in Signal Processing*, vol. 57, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[33] Yan Cui et al., "3D Reconstruction with Spherical Cameras," *IEEE Access*, pp. 1-1, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[34] Ting On Chan et al., "A Method for Turning a Single Low-Cost Cube into a Reference Target for Point Cloud Registration," *Applied Sciences*, vol. 13, no. 3, p. 1306, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[35] Malik Demirhan, and Chinthaka Premachandra, "Development of an Automated Camera-Based Drone Landing System," *IEEE Access*, vol. 8, pp. 202111-202121, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[36] Fatih Altay, and Senem Velipasalar, "The Use of Thermal Cameras for Pedestrian Detection," *IEEE Sensors Journal*, vol. 22, no. 12, pp. 11489-11498, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[37] Rajesh Singh et al., "Internet of Wild Things with the Integration of Vision Technology and LoRa Network," *SSRG International Journal of Electrical and Electronics Engineering*, vol. 10, no. 3, pp. 1-7, 2023. [CrossRef] [Google Scholar] [Publisher Link]