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Enhancing Occlusion Handling in Real-Time Tracking Systems through Geometric Mapping and 3D Reconstruction Validation

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Abstract: Object detection is a classic research problem in the area of Computer Vision. Many smart world applications, like, video surveillance or autonomous navigation systems require a high accuracy in pose detection of objects. One of the main challenges in Object detection is the problem of detecting occluded objects and its respective 3D reconstruction. The focus of this paper is inter-object occlusion where two or more objects being tracked occlude each other. A novel algorithm has been proposed for handling object occlusion by using the technique of geometric matching and its 3D projection obtained. The developed algorithm has been tested using sample data and the results are presented.

Keywords: Computer vision, Image Processing, Object Detection, Occlusion, Reconstruction.

I. INTRODUCTION

In the field of Computer Vision, object recognition technology plays a crucial role in detecting and identifying objects in image or video sequences. Object tracking is the process of continuously following one or multiple objects in a given scene to determine their positions. The main challenge lies in accurately detecting objects across various backgrounds and environments. One specific problem encountered in object detection is occlusion, where the object of interest is partially or fully hidden by other objects or by the viewpoint of the capturing cameras used for pose estimation. Occlusion can occur due to factors like camera angles, resulting in certain parts of an object being visible while others remain hidden. In 3D vision, occlusion has a significant impact on the accurate detection and tracking of objects. This paper introduces a novel algorithm that addresses the detection of occluded objects by employing geometric matching techniques to reconstruct their 3D representations. The remaining sections of the paper are organized as follows:

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Section 2 provides a brief overview of related work in the field. Section 3 presents the proposed algorithm in detail. Section 4 discusses the experimental analysis, including results and discussions. Finally, Section 5 concludes the paper and outlines potential avenues for future research.

II. RELATE WORK

Computer Vision is a multidisciplinary field that encompasses automated image analysis, including image acquisition, processing, analysis, and understanding. Machine Vision (MV) combines automated image analysis with other technologies to enable industrial applications such as inspection and robot guidance [1,12,18]. Machine Vision Systems (MVS) involve cameras capturing images, which are then processed using vision software. The results are compared with predefined standards to determine the appropriate response, such as accepting or rejecting a manufactured part [10,5,8,11,9].

One of the significant challenges in computer vision is detecting occluded objects, especially when objects are grouped together. Occlusions occur when objects are partially or entirely hidden by other objects, resulting in incomplete or obstructed views. Effectively handling occlusions is crucial in real-time tracking systems, as occlusions are common and can hinder object detection [16,1]. Researchers have addressed various aspects of occlusion handling, including occlusion detection, arbitrary viewpoint handling, and texture-less object recognition [2] [3] [4]. However, simultaneously addressing all these factors remains a challenging research problem.

Himanshu et al. conducted a comprehensive review of occlusion handling techniques in object tracking, highlighting different approaches and categories [5,13,14]. Eshed Ohn-Bar et al. explored the problem of occlusion using ensemble detection models and proposed an efficient AdaBoost detection scheme [6]. Tao Yang et al. proposed a novel algorithm to address automatic focus and occluded moving object tracking in complex scenes [7,17,15]. Previous work has also investigated occlusion in 2D vision under various illumination techniques [8,11].

This work specifically focuses on addressing occlusion in 3D vision and reconstruction using a geometric mapping approach. The objective is to overcome the challenges posed by occlusions and accurately perceive and reconstruct objects in three-dimensional space.

By integrating knowledge and techniques from previous works, along with the proposed geometric mapping approach, this research contributes to the development of effective solutions for handling occlusions in real-world scenarios.

III. PROPOSED ALGORITHM

This paper presents a novel algorithm for real-time occlusion handling in object detection. The algorithm specifically focuses on inter-object occlusion, where individual objects may occlude each other. The main contributions of this algorithm include automatic threshold value setup, fine-grained mapping point extraction for modeling features, and 3D reconstruction.

The algorithm consists of the following steps:

- **Reading and cropping the object image**: The image is captured by the camera, cropped, and adjusted to fit within the actual boundary by scaling and rotation.
- **Calculation of score value**: The image is converted into a matrix-like structure for ease of computation. The 3D pose of the object instance is determined, and a match score is computed based on different categories:
- **Score based on surface points**: Weighted count of the number of sampled scene points within a certain distance.
- **Score based on model points**: Number of sampled model points that match with scene points.
- **Score based on point fraction**: Fine-grained score calculation by dividing the score based on model points by the number of models. The score ranges between zero and one.
- **Setting up threshold value**: The threshold value is established based on the score computation. The parameters Minscore and Maxscore are used to filter the results. Matches with a score exceeding Minscore and within or equal to Maxscore are returned. A Min score of 0.3 and Max score of 1 are set as default values.
- **Defining the Region of Interest (ROI)**: Processing regions can be defined using image masks, which determine the pixels to be processed based on their values.
- **Applying scaling to the created shape model**: Once the model is created, the range of possible rotations for the image is determined based on the angle steps, which should be chosen according to the object's size.
- **3D vision:** Data points are aligned in a three-dimensional coordinate system using geometric mapping, enabling 3D reconstruction.

In summary, this algorithm incorporates thresholding and image pyramids for model selection to detect occluded parts. It employs geometric mapping for accurate 3D reconstruction.

Code skeleton has been given below for better understanding of the process flow:

```
# Step a: Reading and cropping the object image
def read_and_crop_object_image():
# Step b: Calculation of score value
def calculate_score(image):
    # Convert the image to a matrix-like structure for ease of computation
    matrix_image = convert_to_matrix(image)
# Calculate the 3D pose of the object instance and compute the match score based on different categories
# Step d: Setting up threshold value
MinScore = 0.3
MaxScore = 1
# Step e: Defining the Region of Interest (ROI)
def define_roi(image, mask):
    # Step f: Applying scaling to the created shape model
def apply_scaling_to_shape_model(model):
# Step g: 3D vision
def extract_3d_points(image):
while True:
    # Capture input image from the camera
    image = capture_image()
    # Step a: Reading and cropping the object image
    object_image = read_and_crop_object_image()
    # Preprocess image if necessary
    # Step b: Calculation of score value
    score = calculate_score(image)
    # Step e: Defining the Region of Interest (ROI)
    mask = create_image_mask(image)
    roi = define_roi(image, mask)
    # Step f: Applying scaling to the created shape model
    shape_model = create_shape_model(object_image)
    scaled_model = apply_scaling_to_shape_model(shape_model)
    # Step g: 3D vision
    extracted_points = extract_3d_points(image)
    # Display the results or perform further processing
    # Check for termination condition or key press to exit the loop
    if termination_condition or key_press:
        break
```

IV. RESULT AND DISCUSSION

This paper is focused on 3D reconstruction of objects in an occluded scenario. The hardware setup used for the experimental analysis is shown in Figure 1.

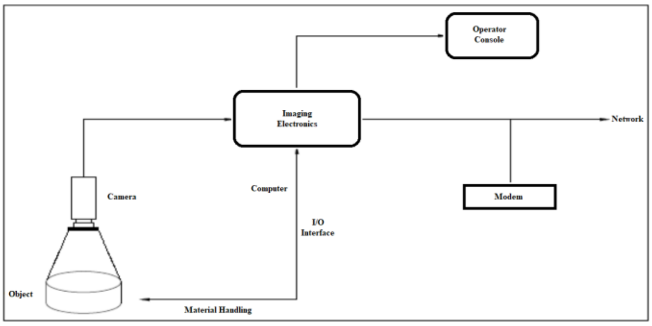


Fig. 1. Hardware setup

In this study, the mV BlueFox monochrome camera with a CMOS sensor was utilized to capture images of objects. The camera offered a resolution of 2488 x 2050, providing high-quality image data.

The image processing tasks were performed using NI LABVIEW 2012, which served as the platform for implementing the proposed algorithm. The algorithm itself was developed in C++ and integrated with the LABVIEW toolbox, combining the advantages of both programming languages.

To implement and evaluate the algorithm, a sample image of a clamp was selected as the input for testing and analysis. This specific image allowed for assessing the algorithm's performance in object detection, recognition, or any other relevant tasks related to clamp analysis.

By leveraging the capabilities of the mV BlueFox camera, along with the image processing capabilities of NI LABVIEW and the algorithm implemented in C++, the research aimed to achieve accurate and efficient processing of the captured image. The choice of the clamp image as a sample input facilitated the evaluation of the algorithm's performance in a practical scenario specifically related to the detection or analysis of clamp objects.

The integration of hardware (camera) and software (NI LABVIEW and C++ algorithm) components provided a comprehensive approach to image processing. This approach allowed the researchers to study and improve various aspects, including image acquisition, processing techniques, and the overall performance of the algorithm.

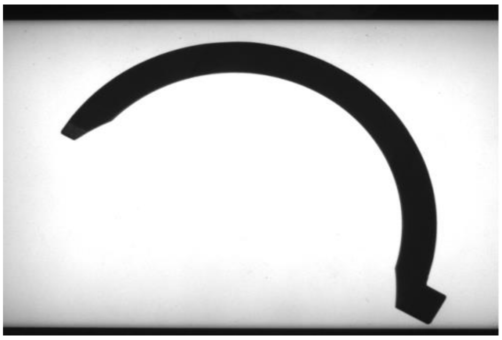


Fig 2. Template image with Back Lighting

In this study, back lighting was chosen as the method for capturing images of the test object. Back lighting offers advantages such as improved contrast and reduced interference from environmental lighting, resulting in clearer and more visible objects in the captured images. This choice was made to ensure better visibility and enhance the accuracy of object detection and analysis.

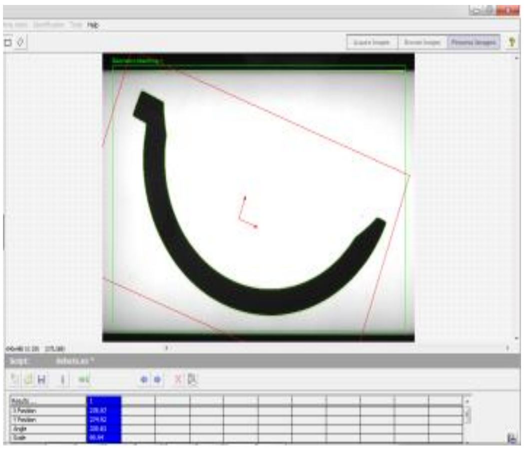
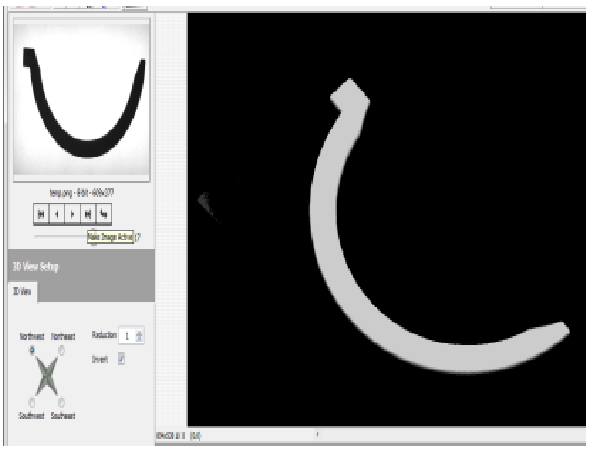
The implemented algorithm was extensively tested using various test objects, including single, double, and multiple occluded objects. The purpose of this comprehensive testing was to evaluate the algorithm's performance in different scenarios, particularly in handling occlusions where objects are partially or fully obscured by other objects in the scene.

During the testing process, images of the test objects were captured under back lighting conditions, and the algorithm was applied to detect and analyze the objects. The output of the algorithm for different occlusion scenarios was recorded and summarized in Table I.

Table I provides a summary of the algorithm's performance in accurately detecting and identifying occluded objects. It offers insights into how the algorithm handles different levels of occlusion, indicating its effectiveness in distinguishing and analyzing objects even when they are partially hidden by other objects.

By conducting thorough testing with various test objects and different occlusion scenarios, the algorithm's robustness and reliability in object detection and analysis can be evaluated. The results presented in Table I demonstrate the algorithm's capability to handle occlusion and provide valuable information for assessing its performance in real-world scenarios.

Table-I. Output for Different Number of Test Objects

Number of objects	Object Detection	3D Reconstruction
1		

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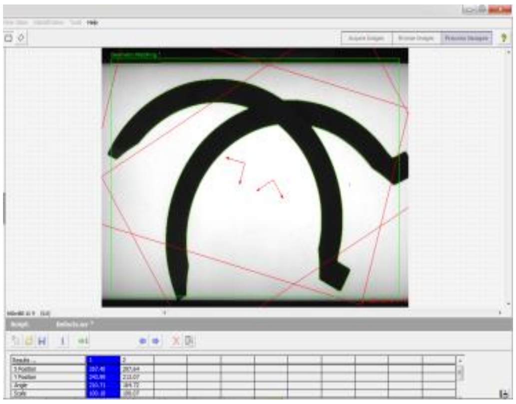
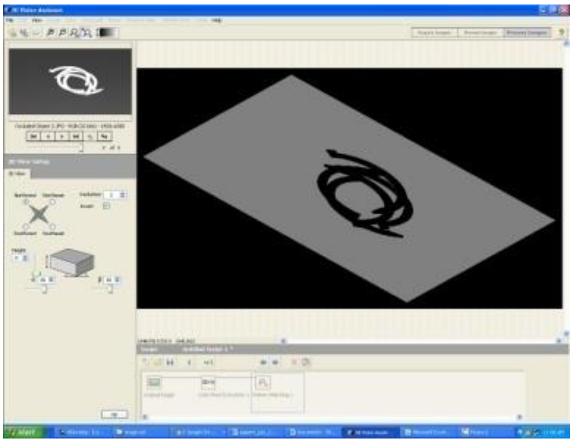
2		
3		

In the images shown in Table I, the red pointer indicates the orientation of the template used for object detection. The computed coordinate values of the object points are then transformed into a 3D view for further validation. The similarity between the view presented in column 2 and the actual image presented in column 1 confirms that the algorithm performs well in detecting occluded objects.

Table II provides detailed information regarding the performance of the proposed algorithm. It likely includes metrics such as detection accuracy, precision, recall, and other relevant measures. These performance metrics give insights into the algorithm's effectiveness in handling occlusions and its overall performance in object detection tasks.

By examining the results presented in Table 2, one can assess the algorithm's performance, its strengths, and areas where improvements may be necessary. This analysis helps in evaluating the proposed algorithm's suitability for real-world applications and guides further research or optimization efforts.

Table-II. Performance of the Algorithm

Object	X	Y	Angle orientation	Match score		Comparison %	Occlusion %
				Segmentation based (MSSB)	Proposed Algorithm (PA)		
1	320.66	220.6	167.01	800	969.52	21.1	17.18
2	342.41	253.07	195.77	729.3	954.83	30.9	23.31
3	362.42	274.33	199.33	720.9	987.87	37.9	73.23

In this study, the coordinate position of the detected object is represented as (X, Y), indicating its location in the image. The angle parameter signifies the 3D orientation of the object. Image matching is performed, and the match score is used to assess the similarity between the detected object and the template. The score values range from 0 to 1000, where a score of 1000 indicates a perfect match, while a score of 0 indicates no match. Table II provides the scores obtained from both the existing algorithm and the proposed algorithm. This comparison allows for an evaluation of the performance improvement achieved by the proposed algorithm. The scores obtained for various test cases are presented in the table, enabling a quantitative assessment of the algorithm's effectiveness in detecting and matching objects. To visualize the comparison more intuitively, a bar chart (Figure 3) is provided, illustrating the scores obtained from both algorithms. The bar chart offers a visual representation of the differences in scores and highlights the performance improvement achieved by the proposed algorithm compared to the existing one. This comparison aids in understanding the algorithm's enhanced matching capabilities and its potential for more accurate object detection.

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By analyzing the scores and the bar chart, researchers and practitioners can gain insights into the algorithm's performance and make informed decisions regarding its suitability for specific applications or further improvements.

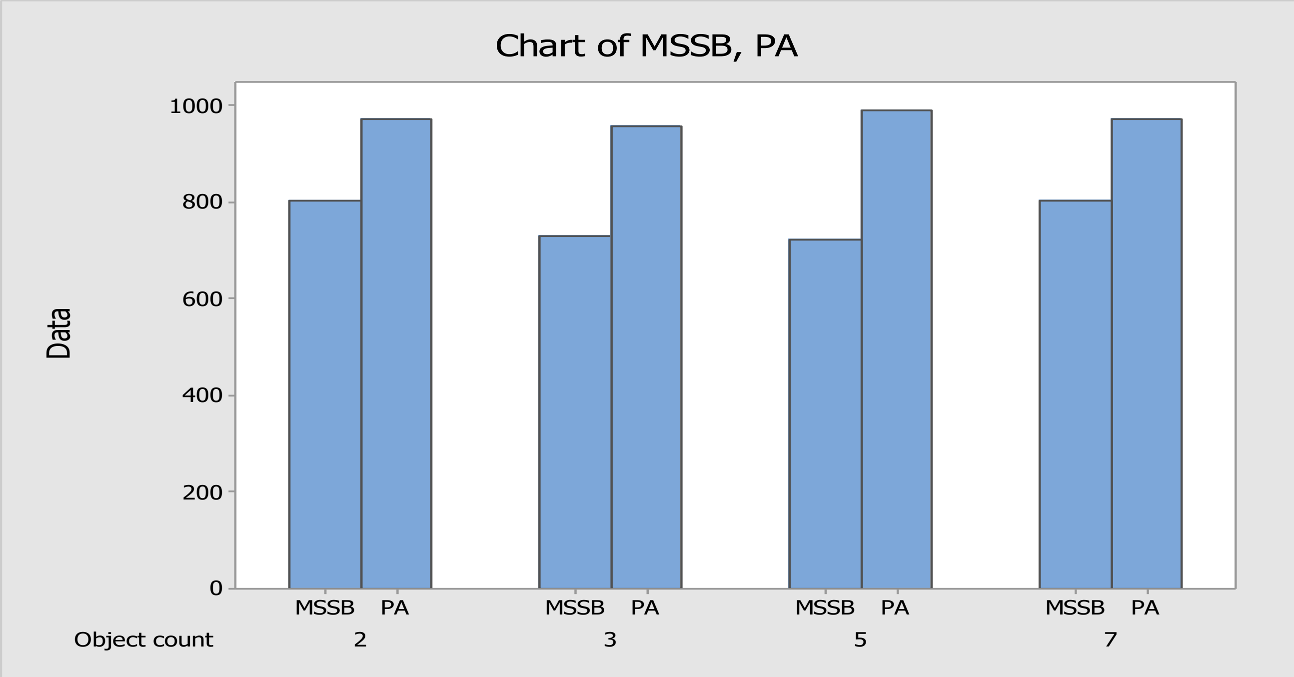

Fig. 3. Match Score (Segmentation Based Vs Proposed Algorithm)

It can be understood from the graph shown in Figure 3, that the scores obtained for the proposed algorithm, the actual score, is higher than the values obtained by the segmentation-based approach. The performance comparison percentage is calculated as:

%Comparison=(Score_proposed-Score_segmentation)/Score_segmentation * 100

The proposed algorithm demonstrates superior performance compared to existing methods, showcasing a remarkable improvement of 20% or more. Table 1 clearly illustrates this superiority, especially in handling occlusion scenarios.

In the case of a single object, the algorithm achieves a relatively low occlusion rate of 17%, indicating its successful detection and analysis capabilities even with minimal occlusion challenges.

However, as the number of objects increases, the occlusion rate significantly rises to around 73%. Despite this high level of occlusion, the proposed algorithm continues to perform well, maintaining accurate object detection and analysis. This robustness in handling multiple inter-object occlusions, even with occlusion percentages exceeding 70%, highlights the algorithm's effectiveness.

The ability of the proposed algorithm to maintain high performance in challenging occlusion scenarios is a valuable advantage. It demonstrates its capability to accurately detect and analyze objects in complex real-world situations where occlusion is common.

These findings emphasize the practical significance of the proposed algorithm in various applications involving object detection and analysis, particularly in scenarios with prevalent inter-object occlusions. Its effective handling of high occlusion percentages opens up possibilities in domains such as video surveillance, autonomous navigation, and object tracking, where occlusion poses significant challenges.

V. CONCLUSION AND FUTURE WORK

This paper focuses on the detection of partially occluded curved objects in object recognition, addressing the challenge of inter-object occlusion. The proposed algorithm presents a novel approach to handle this occlusion, which is critical for achieving accurate object recognition. The results of the algorithm have been presented and discussed, demonstrating its effectiveness in detecting occluded objects.

In terms of future work, there are several potential areas for improvement. One aspect is enhancing the match score, which directly influences the object detection rate. By improving the match score, the algorithm can achieve higher accuracy in detecting objects with different shapes and sizes. This improvement could involve refining the feature extraction and matching techniques and incorporating advanced machine learning algorithms to optimize the scoring mechanism.

Furthermore, the utilization of stereo vision is suggested as a means to enhance the 3D view and reconstruction of detected objects. By employing multiple cameras or viewpoints, stereo vision can provide additional depth information, thereby improving the accuracy of 3D reconstruction. Integrating stereo vision techniques into the algorithm can enhance the representation and understanding of objects in three-dimensional space, leading to more precise object recognition and reconstruction. By addressing these future directions, the proposed algorithm can be further refined and expanded to achieve even better performance in detecting occluded objects.

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Improving the match score and incorporating stereo vision techniques will contribute to more accurate and robust object recognition, benefiting various applications in fields such as robotics, autonomous navigation, and augmented reality.

DECLARATION

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