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Advancing defense capabilities through integration of electro-optical systems and computer vision technologies

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ABSTRACT

The paper comprehensively addresses the integration of advanced technologies to enhance defense capabilities, with a particular focus on critical tasks such as object detection, tracking, and distance measurement. To this end, the integration of IMX219-77 cameras and Nvidia Jetson Nano is proposed, emphasizing the utilization of their respective features. Commonly used tools like open source computer vision (OpenCV) and GStreamer are preferred for ensuring cohesive integration between hardware and software components. On the software front, tools such as OpenCV and GStreamer are preferred for tasks related to computer vision and multimedia processing. The MOSSE algorithm is selected for object tracking due to its speed, efficiency, and resilience to changes in lighting conditions. Additionally, distance measurement is achieved through the use of Stereo Vision techniques. The results of the study demonstrate the effectiveness and accuracy of the proposed integration. It is found that accurate distance measurements with a margin of error ranging from 0 to 2 mm, falling within acceptable limits mentioned in relevant literature, can be achieved. This underscores the efficacy of the proposed technologies for tasks such as object detection, tracking, and distance measurement. The aim of the study is to conduct an in-depth examination of the integration of advanced tools such as IMX219-77 cameras and Nvidia Jetson Nano for use in defense operations. It seeks to showcase how this integration can strengthen defense strategies and provide protection against potential threats. Additionally, the study aims to lay the groundwork for ongoing innovation and development in defense technologies. In conclusion, the integration of electro-optical systems and computer vision technologies has the potential to significantly enhance defense capabilities and contribute to national security efforts. The advantages provided by this integration can serve as a valuable resource for researchers seeking to develop new solutions in defense and security domains.

Keywords: Object detection and tracking, distance measurement, stereo vision, OpenCV, GStreamer

INTRODUCTION

In today's world, the defense industry plays a crucial role in ensuring national security, particularly in strategic tasks such as reconnaissance, threat detection, and target identification. In this context, the use of electro-optical systems holds significant importance. Electro-optical systems, as a perfect combination of light and electronics, provide ideal tools for capturing, processing, and analyzing visual information.

The increasing utilization of electro-optical systems in the defense industry and security applications demonstrates their capability to successfully fulfill strategic tasks such as enemy threat detection, target tracking, reconnaissance missions, and safeguarding security boundaries. The precise and effective use of electro-optical systems is of critical importance for defense strategies. These systems enhance national security by providing high performance in defense operations and offering the potential for effective defense against various threats.

Particularly, the object detection and distance measurement capabilities of electro-optical systems have become one of the primary objectives in the defense industry. Through technologies like stereo camera systems, enemy positions can be identified, threats classified, and strategic tasks such as target identification for fire control systems can be carried out more effectively. Furthermore, open-source computer vision libraries like open source computer vision (OpenCV) are widely used to enhance the efficiency and utilize the potential of electro-optical systems more effectively.

The rapid advancements in computer vision and video surveillance fields are leading to significant breakthroughs in object detection, tracking, and measurement areas. These latest technologies are revolutionizing various sectors such as defense, security, healthcare, and industrial applications. The use of deep learning and computer vision algorithms plays a crucial role in achieving these remarkable outcomes.

Stereo vision technology, involving the use of a pair of cameras to perceive objects in three dimensions, is an impressive and progressive research area that mimics the human visual system. Extensive studies conducted in this field have extensively addressed various aspects of stereo vision systems and algorithms.

Raghunandan and colleagues examined the application areas of various object detection algorithms, simulating and implementing algorithms such as face detection, skin detection, and target detection using MATLAB 2017b. The study also discussed the challenges and applications of object detection methods in fields like defense, security, and healthcare (Raghunandan et al., 2018).

Abdelmoghit Zaarane et al. propose a system for measuring inter-vehicle distances in autonomous driving using stereo camera setup and image processing. The system achieves high accuracy in real-time inter-vehicle distance measurement through vehicle detection, template matching, and geometric calculations (Zaarane et al., 2020).

Abhishek Badki and colleagues investigate rapid object detection within milliseconds and depth approximation through coarse quantization, achieving results comparable to state-of-the-art stereo methods for continuous depth perception. The research contributes to advancing object detection and depth approximation techniques, demonstrating the efficacy of coarse quantization methods in certain scenarios (Badki et al., 2020).

Adam Wacey discusses a stereo camera system comprising an imaging sensor chip and optical device, capable of capturing images side by side and generating volumetric image data based on binocular disparity. The system's image processor constructs three-dimensional volumetric data from imaging frames, identifies moving objects, determines their depth position, and clips volumetric data around them (Wacey, 2020).

Andres Erazo, Eduardo Tayupanta, and Seok-Bum Ko aim to develop a method for object detection in 3D environment navigation using the 2D cameras of mini drones. For this purpose, a TensorFlow network was fine-tuned for specific object classification, and the distances between drones and detected items were measured using epipolar geometry. An average measurement accuracy of 0.6094 was determined, with a processing time of approximately 0.02 seconds for object prediction. The results demonstrate that object detection using 2D cameras can be effectively performed (Erazo et al., 2020).

Ashok Kumar Bandı et al. engineered a specialized system for locations with sporadic human presence, such as bank vaults and residential properties, focusing on identifying intruders to enhance surveillance and security measures, ensuring prompt detection and response to unauthorized access attempts (2023).

Ахметов and colleagues present a system for measuring object distance based on stereo images, providing a brief overview of its purpose, operational algorithm, and performance results (Ахметов et al., 2022).

Elmehdi Adil, Mohammed Mikou, and Ahmed Mouhsen devise a Python-based algorithm for stereo vision systems to measure obstacle distances, demonstrating high accuracy and real-time performance in distance calculation (Adil et al., 2022).

Fan, Rui and collaborators discuss recent advancements in parallel computing architectures to enhance autonomous vehicle perception capabilities, focusing on computer stereo vision. The article provides a comprehensive overview of both hardware and software aspects, contributing to the understanding and advancement of autonomous vehicle perception technology (Fan, 2020).

G. Chandan, A. Jain, H. Jain, and Mohana (2018) focused on real-time object detection and tracking using deep learning and OpenCV (Chandan et al., 2018).

Hamid Laga and collaborators contribute significantly to depth estimation from RGB images, reviewing traditional techniques and advancements in deep learning-based methods. The review highlights the broad applications of depth estimation methodologies across various fields, including robotics, autonomous driving, and medical diagnosis (Laga et al., 2022).

Haydar Yanık and Bülent Turan lay the theoretical groundwork for an industrial image-based measurement device, proposing a novel method for distance detection. The study evaluates the proposed method's accuracy and outlines future work focusing on error detection and hardware-software development (Yanık et al., 2021).

Huei-Yung Lin and colleagues introduced a novel sensor system design for depth recovery based on rotational stereopsis, integrating the rotation of an image sensor to generate visual parallax from multiple viewpoints using a single imaging device, enhancing depth measurement accuracy and flexibility in depth measurement systems, contributing to advancing depth recovery technology (Lin et al., 2021).

In this study, Xiaoxiao Long and colleagues propose a novel method for multi-view depth estimation from a single video frame. Depth estimation plays a crucial role in various applications such as perception, reconstruction, and robot navigation. This study introduces a new Epipolar Spatio-Temporal (EST) transformer to explicitly associate multiple estimated depth maps with geometric and temporal coherence, thus achieving temporally consistent depth estimation (Long et al., 2021).

J. C. Njuguna and collaborators present a novel hardware architecture for the MOSSE tracker algorithm, achieving impressive performance metrics on an FPGA platform. The research contributes to advancing real-time object tracking through efficient hardware implementations of tracking algorithms (Njuguna et al., 2022).

Jia-Yao Su, Che-Ming Wu, and Shuqun Yang develop an innovative deep learning-based algorithm for object tracking, integratinfg motion direction and time series information. The proposed algorithm utilizes a loss function to learn motion direction and employs an attention mechanism for tracking result reliability scoring, enhancing object tracking performance across various datasets (Su et al., 2023).

Ling Bai and colleagues explored the application of OpenCV for face recognition, emphasizing the utilization of cascade classifiers based on Haar-like features and principal component analysis (PCA) of AdaBoost for achieving notable high detection and recognition rates under varying lighting conditions (Bai et al., 2022).

M. A. Dewedar and their team introduced a UAV tracking system implemented using OpenCV, evaluating its performance through a comparative analysis with a real dataset and providing insights into the effectiveness of the UAV tracking system, contributing to advancing UAV tracking technology and highlighting the utility of OpenCV in such applications (Dewedar et al., 2022).

Matteo Poggi and their team address the challenge of stereo matching in computer vision, tracing its evolution and discussing recent trends in learning-based depth estimation. The comprehensive review contributes to the understanding of state-of-the-art techniques in stereo matching and depth estimation (Poggi et al., 2022).

N. Dardagan and colleagues conducted a comprehensive evaluation of seven object trackers implemented in OpenCV, utilizing the MOT20 dataset, aiming to address crucial questions within the field and provide insights into the strengths and limitations of different tracking algorithms, contributing to advancing the understanding and application of object tracking in computer vision (Dardagan et al., 2021).

N. Dardagan and colleagues conducted an evaluation of seven distinct object trackers integrated within the OpenCV library, employing the MOT20 dataset for assessment. The study aimed to ascertain the performance characteristics of various object trackers and discern the specific conditions and object types for which these trackers demonstrate optimal efficacy. This comprehensive evaluation substantially enhances our comprehension of the efficacy of different algorithms within OpenCV for object tracking purposes (Dardagan et al., 2021).

O. Haggui and colleagues presented a recent study focusing on the challenging problem of human tracking in real-world computer vision applications, evaluating OpenCV tracking algorithms' reliability and comparing them with a particle filter algorithm based on color and texture features for pedestrian tracking accuracy in dynamic scenarios, aiming to enhance the performance of human tracking algorithms (Haggui et al., 2021).

Rui Fan and collaborators discuss recent advancements in parallel computing architectures to enhance autonomous vehicle perception capabilities, focusing on computer stereo vision. The article provides a comprehensive overview of both hardware and software aspects, contributing to the understanding and advancement of autonomous vehicle perception technology (Fan, 2020).

S. Ristanto and collaborators developed a stereo camera system using the OpenCV library on the Python platform, capable of providing stereoscopic images and videos in PNG or AVI formats. The system's experimental results demonstrate potential applications in physical measurements, with disparity decreasing as the object moves away from the camera (Ristanto et al., 2021).

Sudhir Khare et al. introduced a study focusing on the development of an image processing technique for measuring the field of view of electro-optical imaging systems, aiming to enhance precision and efficiency through a user-friendly graphics user interface approach (Khare et al., 2021).

Udit Malik highlighted the increasing demand for machine learning techniques in image processing, particularly focusing on leveraging the open-source Python library OpenCV for implementing machine learning algorithms, shedding light on the evolving landscape of computer vision and its practical applications (Malik, 2022).

Xiyan Sun and colleagues propose a method for binocular stereo vision using MATLAB calibration and OpenCV matching, aiming for efficient and precise non-contact detection and quality control. By calibrating and rectifying stereo cameras, the method computes object distances based on acquired disparity values, demonstrating effectiveness in meeting distance measurement requirements (Sun et al., 2019).

Xucheng Wang and colleagues propose a convolutional neural network wintegrating epipolar geometry and image segmentation for light-field depth estimation. The method achieves high rankings in quality assessment metrics and accurately predicts depth from real-world light-field images (Wang et al., 2020).

Yandong Liu developed a novel object identification method tailored for industrial robots, leveraging image processing techniques, which efficiently detects objects amidst varied backgrounds, determines their distance from the camera, and tracks their motion direction using Python-based OpenCV algorithms (Liu, 2023).

Zaarane et al. propose a system for measuring inter-vehicle distances in autonomous driving using stereo camera setup and image processing. The system achieves high accuracy in real-time inter-vehicle distance measurement through vehicle detection, template matching, and geometric calculations (Zaarane et al., 2020).

Recent advancements in areas such as image processing, stereo vision technology, deep learning, and object tracking have led to significant innovations in the defense industry and other sectors. These advancements contribute to strengthening national security and public safety by enhancing the performance of electro-optical systems.

In conclusion, the significance of electro-optical systems and image processing technologies in the defense industry and security applications is undeniable, marking a field that continues to evolve and improve. The adept use of these technologies plays a pivotal role in upholding national security and ensuring public safety.

METHODS

Outlined in this section are the software and hardware tools chosen to fulfill the objectives of object detection, tracking, and distance measurement within electro-optical systems.

The decision to merge two IMX219-77 cameras with Nvidia Jetson Nano for this study stemmed from various factors.

Primarily, the IMX219-77 camera's high resolution and expansive field of view render it perfect for tasks such as object detection and recognition. Its detailed image capture capability and heightened sensitivity in detecting objects are paramount. Furthermore, the broad field of view empowers the cameras to effectively scan diverse environmental conditions and detect objects across a wide area.

Secondly, the adoption of a low-power yet high-performance platform like Jetson Nano presents an apt solution for real-time image processing needs. Leveraging Jetson Nano's GPU-accelerated computing prowess allows for swift execution of intricate image processing algorithms, thereby augmenting application performance. Additionally, its low power consumption ensures prolonged battery life, ideal for portable devices.

Lastly, the amalgamation of IMX219-77 cameras and Jetson Nano yields a compact and portable solution. This integrated system proves optimal for mobile and embedded applications where device size, weight, and portability are paramount. As a unified system, it facilitates seamless assembly and usage, offering heightened efficiency when deployed together.

For these reasons, the combination of IMX219-77 cameras and Nvidia Jetson Nano is an ideal choice for electro-optical system applications such as object detection, tracking, and distance measurement.

In the realm of software, the decision was made to employ OpenCV and GStreamer. This choice stems from several key reasons:

Firstly, OpenCV library stands as a widely adopted open-source framework for developing computer vision and image processing applications. Offering an extensive array of tools and algorithms, it supports fundamental and advanced operations such as image and video processing, object detection, and feature recognition. Its comprehensive toolset and wide user base provide developers with flexibility, efficiency, and robustness in various applications.

Secondly, GStreamer serves as an open-source multimedia framework specifically designed for multimedia processing tasks. It excels in tasks such as manipulation, conversion, and processing of video and audio streams. Additionally, its capability to utilize GPU acceleration enhances its performance, particularly in real-time video processing applications. The integration of GStreamer complements the functionality provided by OpenCV and addresses potential issues related to frame rates, thereby ensuring smooth and efficient processing (Manolescu et al., 2024).

For target detection and distance measurement, the MOSSE and Depth Estimation (Stereo Vision) algorithms have been selected.

By leveraging these algorithms and software tools, the study aims to achieve robust and efficient object detection, tracking, and distance measurement capabilities within electro-optical systems.

MOSSE is a tracking algorithm used for object tracking purposes. The MOSSE algorithm learns the characteristics of an object from a specified region and then tracks the object using these learned features. Named after the expression MOSSE, the algorithm focuses on minimizing the sum of squared errors obtained during the object tracking process. The main advantages of the MOSSE algorithm are:

- Fast Tracking: MOSSE is optimized for real-time object tracking applications. By employing fast and efficient computation methods, it can track objects at high speeds.
- Requires Less Training Data: MOSSE can utilize a small amount of training data to learn the object's features. This advantage allows for more efficient utilization of memory and computational resources.
- Resilient to Lighting Changes: The algorithm is resistant to changes in lighting conditions, enabling it to cope with lighting variations that may occur during object tracking.

The MOSSE algorithm is commonly used in security systems, automatic tracking systems, and video analytics applications.

Depth Estimation (Stereo Vision) is the process of obtaining depth information about objects in a scene. Stereo vision attempts to acquire distance information of objects by analyzing images captured from a pair of cameras. The lateral separation between the two cameras enables the generation of a three-dimensional representation.

The stereo vision process includes the following steps:

- Computing Epipolar Geometry: Determining the epipolar geometry between the two cameras is essential for associating the positions of points in the images and consequently calculating depth information.
- Generating Disparity Maps: A disparity map is created to identify differences between the two images. Disparity represents the horizontal distance between a point's position in one image and its position in the other image.
- Creating Depth Maps: Using the disparity map, the depth of each point in the scene is computed. Depth information is typically obtained using stereo camera calibration and epipolar geometry.

Stereo vision finds applications in various fields such as autonomous vehicles, robotics, augmented reality, and virtual reality. This technique provides an important tool for understanding object distances and improves positioning and detection in various applications.

Proposed Algorithm

The image captured from the IMX219-77 cameras is transmitted to the Jetson Nano via a video stream created using Gstreamer. Subsequently, the received image data is captured with OpenCV and converted into the appropriate format, then compared with a database within a function capable of detecting and recognizing objects. During this comparison process, the MOSSE algorithm actively plays a crucial role. Once the target is detected, one of the images remains normal while the other is converted into a depth map using Stereo Vision. In this process, the images obtained from the two cameras are horizontally mapped, and the depth information obtained from the calculations provides us with the distance between the object and the camera. Finally, the processed image is displayed on the screen, completing the process, as shown Figure 1.

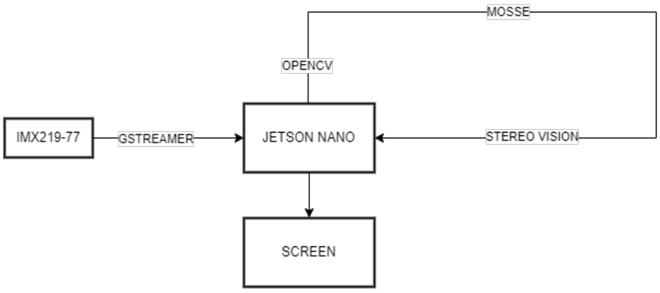

Figure 1. The block diagram of the system

A depth map is created using the stereo vision technique. In this process, two cameras are aligned horizontally, parallel to each other, and at a fixed distance. The depth of objects is calculated using the parallax difference between the images obtained from the cameras. Epipolar geometry is utilized to generate the depth map. Epipolar geometry is a concept that geometrically defines the relationship between two cameras. This relationship is expressed through geometric structures such as epipolar lines, epipolar planes, and the fundamental matrix. The principles of epipolar geometry are used to estimate the possible location of an object from an image captured by one camera in the image captured by the other camera.

Disparity refers to the difference in pixel positions between different cameras in stereo vision systems. This difference is utilized to determine the depth of objects and is a crucial measurement in stereo vision systems. In Figure 2, it is observed as: (OpenCV, 2024)

$$disparity = x - x' = \frac{BF}{D} \qquad (1)$$

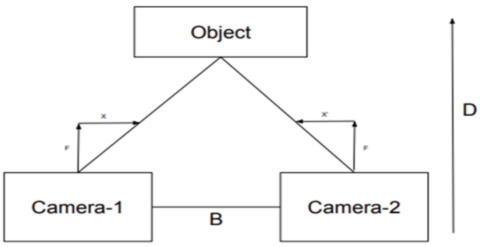

Figure 2. At the focal point of two cameras: depth and distance measurement

Here, 'B' denotes the inter-camera distance, 'F' represents the focal length of the lenses, and "x-x'" indicates the difference in pixel positions of the object in the image. In practice, the focal length 'F' and inter-camera distance 'B' are often unknown and manual measurement may lead to errors. Therefore, the Least-Squares method is employed.

The Least-Squares method minimizes errors in a dataset to find a model that best represents the relationship between data points. By minimizing the sum of squared errors between data points, this method determines a line or curve. Using the Least-Squares method, a parameter 'M' is derived, which is set equal to the product of 'B' and 'F'.

To incorporate this equation into the software algorithm, it is transformed into a Linear Regression expression.

$$x - x' = \frac{M}{D} \qquad (2)$$

The smaller focal length results in larger disparity and better perception of object depth. Increasing the distance between cameras (baseline) leads to an increase in disparity, enhancing the perception of distant objects. Since the focal length of the IMX219 cameras is 2.85 mm and remains constant, the relationship between disparity and depth has been examined based on the distance between the cameras.

Linear Regression is used to model the relationship between a dependent variable and one or more independent variables. Its aim is to predict the dependent variable given the values of the independent variables. This method expresses relationships in the dataset with a linear model, best fitting the data points. As seen in Equation-3, our dependent variable 'D' and independent variable '(x-x')' are used to model situations where a linear relationship exists in the operation, finding the 'M' parameter that best fits the data points to this linear model.

$$D = \frac{M}{x - x'} \qquad (3)$$

To be used within the software algorithm:

$$a = \frac{1}{x - x'} \qquad (4)$$

Equation is equated and the equation:

$$D = M \ x \ a \qquad (5)$$

is obtained (OpenCV,2024).

Normally, for a single image frame, this equation can provide reliable results with a very low error rate. However, in real-time camera systems during the calculation/measurement of depth (D) and disparity (a) values, errors may occur manually or through algorithms. Hence, to find the most suitable values, OpenCV's "solve()" function is employed. Upon running the function, once the 'M' value is found, the depth value is determined using Equation-6.

$$D = \frac{M}{disparity} \qquad (6)$$

When looking at Figure 3, disparition measurements of two different stereo camera systems with focal length of 2.96 mm and pixel size of 1.12 µm and two different Baseline values (30 mm and 80 mm) were compared by examining five different depths ranging from 230 cm to 70 cm. The results are as follows:

Distance Perception: Increasing the Baseline length increases the parallax difference between objects. This leads to an increase in the disparition perceived by the stereo imaging system and allows for a more precise measurement of the distance between objects. Conversely, decreasing the Baseline length reduces the parallax difference and makes the distance perception less precise.

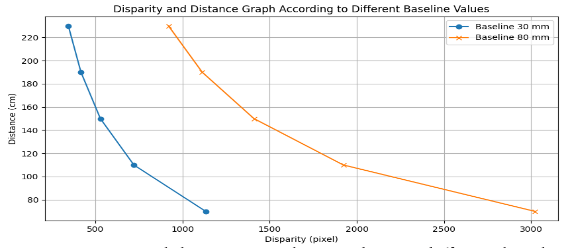

Figure 3. Disparity and distance graph according to different baseline values

Depth Perception: Stereoscopic imaging systems calculate the depth of objects based on disparition. Increasing the Baseline length enhances the depth perception, making the difference in depth between objects more pronounced. However, an excessively large Baseline value can overly sensitize the depth perception and result in unnecessary details. On the other hand, decreasing the Baseline value reduces the depth perception and makes the difference in object distances less pronounced.

Field of View and Perspective: Increasing the Baseline length narrows the field of view and alters the perspective. This may cause the stereo imaging system to focus on a narrower area and have a more distinct perspective. Conversely, decreasing the Baseline length widens the field of view and leads to a less distinct perspective.

The Figure 4 displays the inverse disparity values for objects at different distances. Inverse disparity is a measure used in stereo vision systems to calculate depth information from images taken from different viewpoints and is the mathematical inverse of disparity. Disparity is the horizontal position difference of the same point in images taken by two cameras, and inverse disparity is the inverse of this value. That is, the larger the disparity, the smaller the inverse disparity, and vice versa.

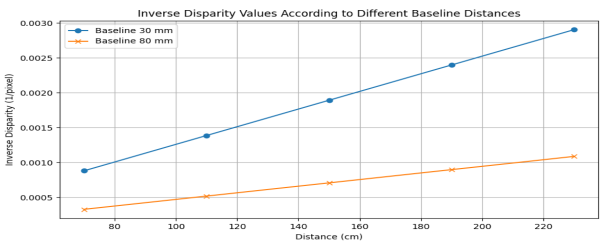

Figure 4. Inverse disparity and distance graph according to different baseline values

In the graph, the x-axis represents distance in centimeters, and the y-axis represents inverse disparity in units per pixel. The values of inverse disparity for two different baseline distances are shown: 30 mm and 80 mm. As the distance increases, both lines show an increase in inverse disparity values, but at different rates.

This graph is particularly useful for applications such as 3D reconstruction, where choosing the correct baseline distance is crucial for accurate depth estimation. It shows that as the baseline distance increases, the rate of increase in inverse disparity also goes up. This indicates that longer baseline distances can provide more precise depth measurements for closer objects. However, this also means that disparity becomes harder to detect for more distant objects, as smaller disparity values lead to larger inverse disparity values, making the depth estimation less precise.

According to the academic literature, a margin of error of 3% is generally considered acceptable. Similar results were obtained in the study conducted by Uğur Can Boz and İdris Sancaktar (2023), where they detected vehicle chassis deformities using stereo imaging (Boz & Sancaktar, 2023). Another study by Zelin Meng and colleagues presents a lightweight depth estimation method based on binary vision technology using ORB features and brute-force matching. This method predicts camera movement and estimates depth using triangulation theory based on the pixel coordinates of matching point pairs, providing high accuracy and real-time performance (Meng et al., 2021). R. Arokia Priya Charles and Anupama V. Patil proposed a methodology for object detection using a dual-camera system. The developed method processes images using thresholding and blob detection techniques to find the centers of objects and accurately determine their distances using stereographic depth values (Charles et al., 2021).

The results obtained in the study fall below the threshold mentioned in the academic literature and are consistent with the examples. A margin of error ranging from 0 to 2 mm was observed at distances between 70 and 230 cm in the x-y plane.

RESULTS

In this study, it has been observed that the integration of electro-optical systems, deep learning algorithms, and computer vision technologies significantly enhances the capabilities of defense and security applications. Through the utilization of stereo vision technology and advanced object detection methods, defense strategies can effectively identify threats, track targets, and conduct reconnaissance missions with precision and efficiency. This establishes a fundamental understanding of the importance of electro-optical systems in defense strategies, emphasizing their critical role in safeguarding national security by enabling essential tasks such as reconnaissance, threat detection, and target identification. Similarly, the combination of IMX219-77 cameras and Nvidia Jetson Nano, coupled with OpenCV and GStreamer, in this study has demonstrated remarkable performance in object detection, tracking, and distance measurement tasks. The MOSSE algorithm, utilized for object tracking, has proved to be robust and efficient, while stereo vision techniques have enabled accurate depth estimation crucial for defense operations. The findings of this research, falling within acceptable error margins, underscore the reliability and effectiveness of the implemented techniques. With a margin of error of 0-2 mm observed in the x-y plane, the study provides valuable insights into the practical application of electro-optical systems for defense purposes.

DISCUSSION

This study demonstrates that the integration of electro-optical systems, deep learning algorithms, and computer vision technologies significantly enhances the capabilities of defense and security applications. Through the utilization of stereo vision technology and advanced object detection methods, defense strategies can effectively identify threats, track targets, and conduct reconnaissance missions with precision and efficiency. This establishes a fundamental understanding of the importance of electro-optical systems in defense strategies, emphasizing their critical role in safeguarding national security by enabling essential tasks such as reconnaissance, threat detection, and target identification.

Similarly, the combination of IMX219-77 cameras and Nvidia Jetson Nano, coupled with OpenCV and GStreamer, in this study has demonstrated remarkable performance in object detection, tracking, and distance measurement tasks. The MOSSE algorithm, utilized for object tracking, has proved to be robust and efficient, while stereo vision techniques have enabled accurate depth estimation crucial for defense operations. The findings of this research, falling within acceptable error margins, underscore the reliability and effectiveness of the implemented techniques. With a margin of error of 0-2 mm observed in the x-y plane, the study provides valuable insights into the practical application of electro-optical systems for defense purposes.

The results of this study, when compared with previous research conducted in the literature, indicate similar outcomes. For example, many previous studies have emphasized the importance of stereo vision techniques and object detection algorithms in defense and security applications (Zaarane et al., 2020; Raghunandan et al., 2018). These studies have demonstrated the critical role of electro-optical systems in defense operations, such as threat detection, target tracking, and reconnaissance missions.

Additionally, the results of this study highlight the reliability and effectiveness of stereo vision techniques and object detection algorithms. Specifically, it has been observed that the MOSSE algorithm provides fast and efficient object tracking, while stereo vision techniques enable accurate depth estimation. These findings suggest that electro-optical systems are a critical component in defense and security applications, and the proper integration of these technologies enhances operational capabilities.

While the selection of hardware and software components has been carefully made, it is essential to acknowledge the limitations of the technologies employed. For instance, although the choice of IMX219-77 cameras and Nvidia Jetson Nano offers specific advantages in terms of resolution and computational power, the exclusion of other alternatives may limit the scope of the research.

For instance, further research may be needed to determine the effectiveness of the algorithms and techniques under specific conditions. Additionally, since this study only evaluated a specific hardware and software configuration, different results may be obtained on different platforms and applications. By utilizing more powerful software and hardware components, advancements in this field of study can be further pursued. And also, future research can contribute to a better understanding of the potential in this area by further developing these technologies and testing them in different applications.

CONCLUSION

The study's findings highlight the significant advancements achieved through the integration of electro-optical systems, deep learning algorithms, and computer vision technologies within defense and security applications. Utilizing stereo vision technology and sophisticated object detection methods, defense strategies can now efficiently identify threats, track targets, and conduct reconnaissance missions with precision. This research establishes the critical role of electro-optical systems in safeguarding national security by enabling essential tasks such as reconnaissance, threat detection, and target identification. Specifically, the combination of IMX219-77 cameras and Nvidia Jetson Nano, alongside OpenCV and GStreamer, has demonstrated remarkable performance in object detection, tracking, and distance measurement tasks. The robustness and efficiency of the MOSSE algorithm for object tracking, coupled with accurate depth estimation enabled by stereo vision techniques, underscore the reliability and effectiveness of the implemented methodologies. With observed error margins falling within acceptable ranges, the study provides valuable insights into the practical application of electro-optical systems for defense purposes, including a margin of error of 0-2 mm in the x-y plane. Moreover, by leveraging the potential of electro-optical systems and computer vision algorithms, defense strategies can be fortified to mitigate risks and safeguard against potential threats effectively. Furthermore, the study's forward-looking perspective emphasizes its contribution to future research and development in defense technologies, offering insights and methodologies for further advancements in object detection, tracking, and measurement techniques. This research also underscores the rapid advancements in computer vision and video surveillance technologies, showcasing their transformative impact not only within defense and security sectors but also across various industries including healthcare and industrial applications, thus reflecting their broader implications and potential.

ETHICAL DECLARATIONS

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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