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Efficient Battery Management and Workflow Optimization in Warehouse Robotics through Advanced Localization and Communication Systems

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INTRODUCTION & AIM

- **Autonomous Guided Vehicles (AGVs)** are self-operating robotic systems widely used for material handling in controlled environments. Their integration into smart manufacturing systems enhances production efficiency by automating logistics workflows, reducing labor costs, increasing throughput, and improving safety.

- Key Technologies such as color detection for **Image segmentation and localization methods are essential for AGVs**. These technologies enable precise navigation by avoiding obstacle to make a safer working environment.

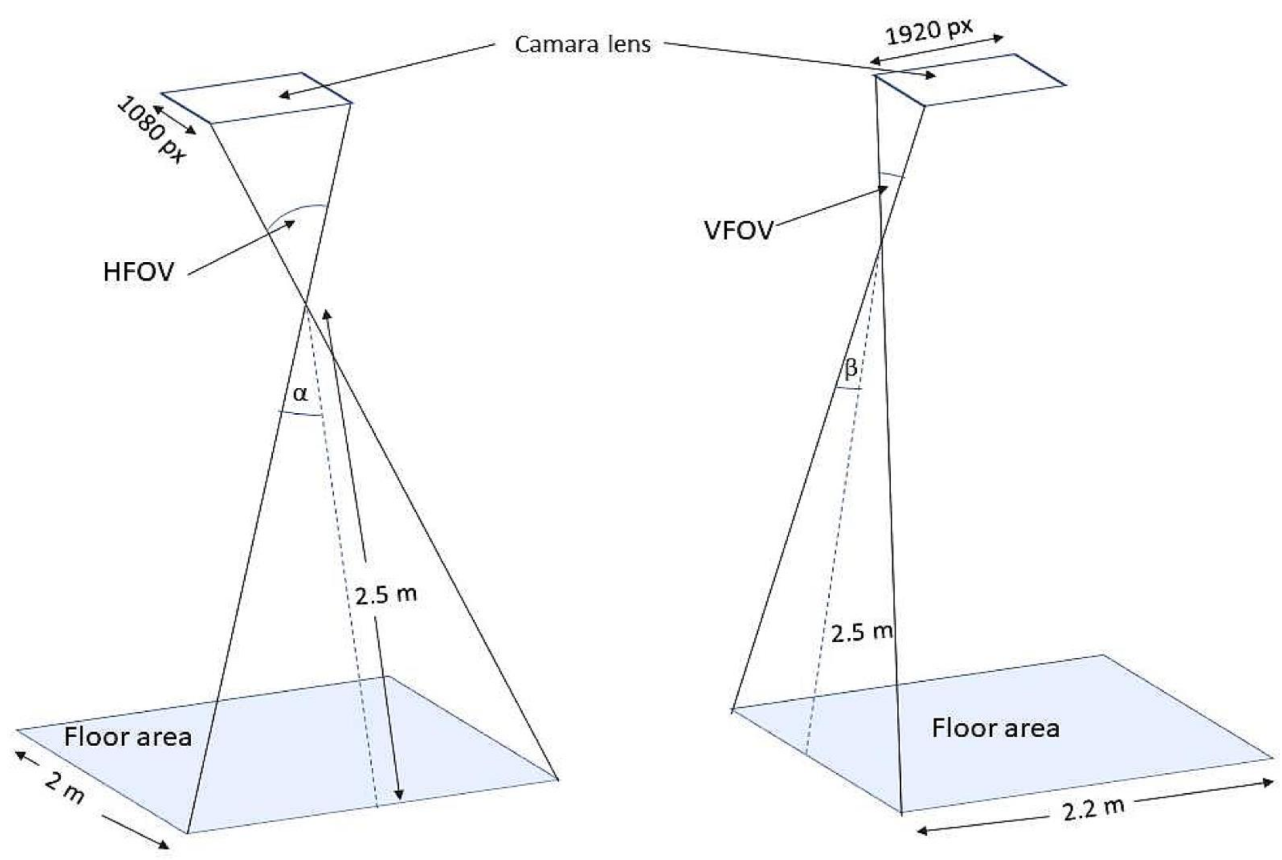
- **Path planning algorithms like A* are vital for finding collision-free routes in dynamic environments**, while wireless communication ensures high-speed data exchange, enhancing UGV control and mobility maintaining a strong communication link between the main controller and mobile robots..

- A significant gap in AGV operations is the lack of automated battery management and real-time task reassignment. This study proposes an advanced system combining localization, wireless communication, and battery management to minimize downtime. It includes real-time task transfers between robots and monitoring via a custom-designed GUI to ensure uninterrupted workflow and increased productivity.

METHOD

- A general-purpose webcam is mounted at a height of 2.5 m, capturing a floor area measuring 2 m horizontally (HFOV) and 2.2 m vertically (VFOV). The camera has a resolution of 1920 pixels horizontally and 1080 pixels vertically, allowing detailed image capture.

- To ensure efficient real-time processing at 30 FPS, the captured frame is simplified by converting each 10 × 10-pixel cell into a single data point. The cell is marked as 0 or 1 based on whether the majority of pixels are zeros or ones, creating a streamlined matrix for further analysis.

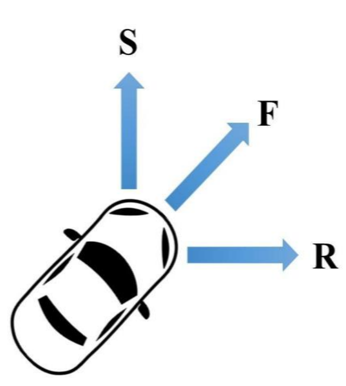


- Object edges are expanded by two positions around areas marked as zeros to improve detection accuracy and prevent collisions during UGV navigation. The HFOV and VFOV angles (α and β) are calculated based on the camera's setup, enabling precise pixel mapping of the floor area. Each square meter of the floor is converted into corresponding pixel values, facilitating accurate object detection and tracking.

- By analyzing the relationship between pixel data and the floor area, this setup effectively determines the position and movement of objects within the camera's view. This mapping process ensures precise navigation and enhances UGV operations in the defined environment.
- Uses HSV thresholding with calibrated values to isolate specific colors and identify contours for UGV location and direction.

- Incorporates A* algorithm for navigation, treating expanded areas as obstacles for collision-free route planning.

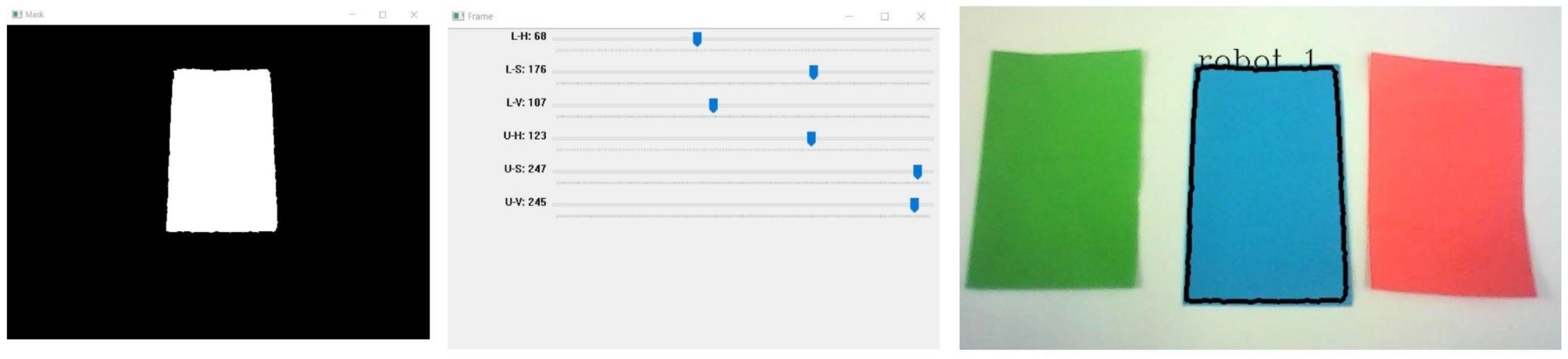
- Coordinates and movement commands guide UGVs efficiently.
  F (forward),
  R (45° clockwise),
  S (stop),
  E (45° counterclockwise)



RESULTS & DISCUSSION

- By adjusting the lower and upper HSV values, specific colors are isolated from the images, while others are excluded enabling real-time object and contour detection through color segmentation.

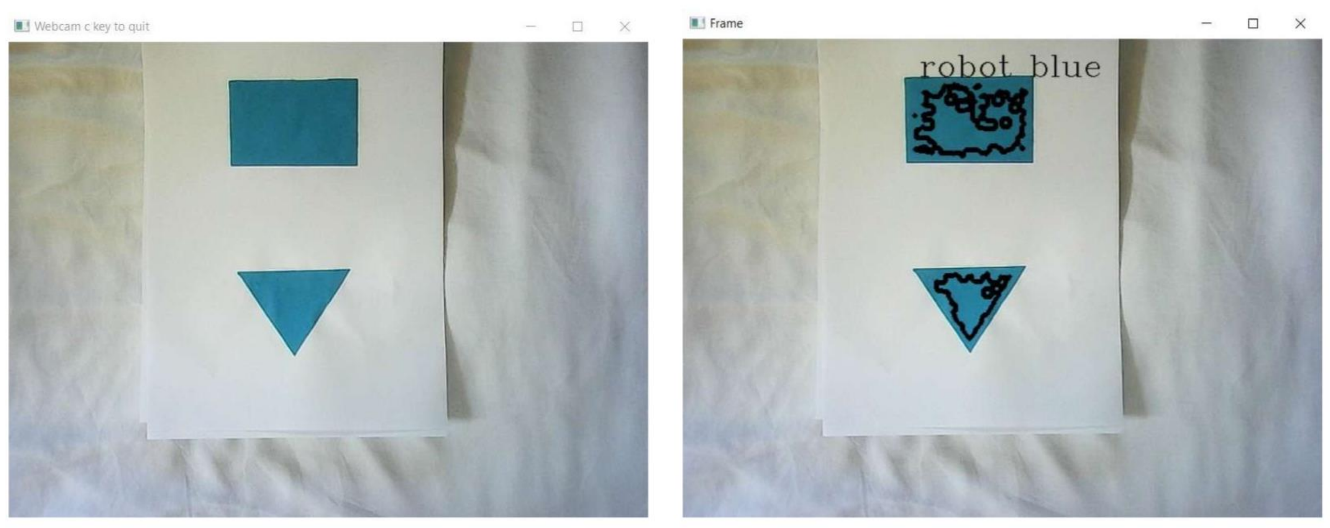
- Although fine-tuning these values improves accuracy, the use of a general-purpose webcam introduces limitations such as color shifts.



(a) (b) (c)

- A generated mask is used to filter colors, and morphological operations refine the results. Lighting conditions, including natural light variations, significantly impact color calibration, making controlled artificial lighting essential for accurate detection.

- Additionally, noise factors like shadows, reflections, and illumination variations must be managed for clear image quality.



(a) (b)

- Threshold values for each color are determined using GUI-based trackbars for real-time object and contour detection via color segmentation algorithms.

- Lower and upper HSV values isolate specific color ranges, excluding irrelevant pixels. Fine-tuning HSV values improves accuracy but is limited by general-purpose webcams.

- Generated masks filter colors, further refined through morphological operations.

- Lighting conditions, including natural light and noise factors like shadows and reflections, significantly influence detection accuracy.

- Controlled artificial lighting is essential for reliable color representation and minimizing interference.

CONCLUSION

This study developed a Warehouse Robot Localization and Communication System to optimize battery management and improve workflow efficiency in warehouses. The system integrates advanced localization algorithm, and a wireless communication network, enabling real-time task reassignment and automated battery monitoring. This minimizes downtime and reduces manual intervention. Experimental results confirmed its effectiveness in maintaining uninterrupted operations and enhancing productivity. With further improvements, such as higher-resolution cameras and robust communication protocols, the system shows strong potential for practical applications in Industry 4.0. The accuracy of the system can be improved by integrating multiple cameras.

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