Drone Collision Avoidance

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***Abstract*—Collision avoidance in drones plays a crucial role in warehouse management, where drones are increasingly utilized for various tasks such as inventory management, order picking, and logistics. In this paper, we present a drone collision avoidance system developed using the Webots simulation environment. The system aims to enhance the safety and efficiency of drone operations within warehouse facilities. By integrating sensors and algorithms, our approach enables drones to autonomously navigate through dynamic environments while avoiding collisions with obstacles and other drones. We evaluate the performance of our collision avoidance system through extensive simulations, considering factors such as obstacle density, drone speed, and environmental conditions. Our results demonstrate the effectiveness of the proposed system in reducing the risk of collisions and improving overall warehouse productivity. This research contributes to the advancement of drone technology in warehouse management and highlights the importance of collision avoidance mechanisms for safe and reliable drone operations in industrial settings.**

***Index Terms*—Drone collision avoidance, Warehouse management, Webots simulation, Autonomous navigation, Industrial robotics**

I. Introduction

In recent years, drones have emerged as a disruptive technology revolutionizing various industries and sectors. From aerial photography and surveillance[1] to agriculture[2] and disaster relief[3,4,5], drones have showcased their versatility and adaptability in diverse applications. Their ability to access remote or hazardous environments, gather real-time data, and perform tasks autonomously has garnered significant attention from researchers, businesses, and policymakers worldwide. As drones continue to evolve and integrate advanced technologies such as artificial intelligence (AI) and machine learning (ML), their potential to reshape traditional processes and workflows becomes increasingly apparent.

With the integration of AI capabilities, drones are not only becoming smarter but also more autonomous. However, this advancement raises important ethical considerations regarding responsible AI usage. As drones operate in complex environments and interact with human populations, ensuring ethical behavior and adherence to regulatory guidelines is paramount. Ethical AI principles such as transparency, fairness, and accountability must be embedded into drone systems to mitigate risks and foster trust among stakeholders. By prioritizing responsible AI practices, drone operators can leverage the full potential of this technology while minimizing negative impacts on society and the environment[6,7,8].

One area where drones have demonstrated immense potential is warehouse management. Traditionally, warehouse operations rely on manual labor and conventional methods for tasks such as inventory management, order fulfillment, and facility maintenance. However, these methods are often time-consuming, labor-intensive, and prone to errors. In contrast, drones offer a more efficient and cost-effective solution for streamlining warehouse operations. By leveraging drones equipped with sensors, cameras, and AI algorithms, warehouses can automate inventory tracking, optimize storage space, and enhance overall logistics efficiency. In this paper, we explore the application of drones in warehouse management and compare their performance with traditional methods to highlight the advantages and challenges of adopting drone technology in industrial settings.

II. Related Work

A. Drone Warehouse Management

Drones have emerged as a disruptive technology with the potential to transform various industries, including warehouse management. Ali et. al. highlight the socio-economic benefits of drones in smart warehouse management, emphasizing their efficiency, safety, and economic advantages. Their study investigates the enablers impacting drone applications in warehouse operations, identifying key factors through literature review and empirical methods. Malang et. al.[9] emphasize the significance of unmanned aerial vehicles (UAVs) in warehouse operations, noting their role in automating processes such as receiving, picking, storage, and shipping. Their systematic literature review (SLR) identifies critical factors affecting UAV adoption in warehouse management, with hardware and software considerations emerging as key influencers. Benes et. al.[10] address the challenge of inventory management in large outdoor warehouses and propose the use of UAVs for product identification. Their study focuses on determining the optimal flight level for UAVs to distinguish identified items efficiently, highlighting the potential of drones in inventory management tasks.

Rhiat et. al.[11] present a prototype called "Smart Shelf" for simulating a smart warehouse environment, integrating mobile robots with grippers managed by ROS (Robotic Operating System) and RFID technology for stock management. Their research aims to minimize human intervention and optimize warehouse operations through automation. Piramuthu[12] examines the role of drones and object-level RFID tags in automating inventory management, particularly in warehouses handling perishable goods. Their study showcases the value of automation in reducing wastage and enhancing efficiency in warehouse operations. Manjrekar et. al.[13] propose a drone-based inventory management system equipped with Wi-Fi and camera modules for barcode scanning and navigation. Their approach aims to improve accuracy and reliability in inventory tracking within warehouses, offering a cost-effective solution for industrial applications. Yoon et. al.[14] focus on the application of drones for inventory management in warehouses and storage yards. They propose a position estimation method based on QR code segmentation to facilitate efficient inventory tracking in dynamic environments.

Chen et. al.[15] introduce a warehouse management system with UAVs based on digital twin and 5G technology. Their system aims to address challenges such as imperfect information exchange and manual cargo inventory through real-time data processing and remote control capabilities.

B. Drone collision avoidance

Intersections of flight paths in multidrone missions serve as indicators of a heightened risk of in-flight drone collisions, necessitating proactive measures during path planning. For instance, Shen et al.[16] propose two offline collision-avoidance multidrone path-planning algorithms, DETACH and STEER. These algorithms are designed to optimize the flight paths of multiple drones, with each drone tasked with completing specific segments of a larger mission. By dividing large drone tasks into smaller, more manageable components, the overall efficiency and effectiveness of the mission can be enhanced. Notably, these algorithms prioritize maximizing waypoint coverage, a crucial aspect of mission success. DETACH and STEER employ vector intersection checks for flight path analysis at different stages of path planning, ensuring comprehensive collision avoidance strategies.

Similarly, Je-Kwan et. al.[17] explores novel algorithms for collision avoidance and local path re-planning in dynamic environments using rapidly-exploring random tree (RRT) methods. For example, the boundary-RRT* algorithm offers a unique approach to aerial vehicle navigation by bounding the configuration space and incorporating implicit biases. By reducing the exploring space and incorporating right-of-way rules, the algorithm can efficiently navigate three-dimensional environments while maintaining a natural path curvature. Additionally, the algorithm's stability and reliability are highlighted through numerical analysis, demonstrating its suitability for real-time collision avoidance and path re-planning. Yasin et al.[18] address the intricate relationship between collision avoidance mechanisms and formation control strategies in swarm drone navigation. For instance, they propose a method for formation-collision co-awareness that minimizes deformation of the swarm's formation while avoiding obstacles. By utilizing non-rigid mapping functions, the proposed methodology reduces response times and improves energy efficiency, enhancing the overall performance of the swarm in dynamic environments.

Furthermore, Zhang et al.[19] present a fusion scheme for autonomous drone collision-free path planning, considering both static obstacles and dynamic threats. Their approach combines 3D voxel jump point search (JPS) based path planning with a local collision resolution method based on the Markov decision process (MDP). Through simulations, the proposed model demonstrates its effectiveness in achieving autonomous path planning and real-time collision resolution for multirotor drones in complex environments. Additionally, Adarsh et al.[20] explore collision-free drone-based movement strategies for road traffic monitoring using Software Defined Networking (SDN). By utilizing SDN-controllable drone networks, the proposed approach reduces overhead and increases area coverage, enhancing the efficiency of traffic monitoring systems. Finally, Jacob et al.[21] propose an effective collision avoidance system using drones with swarm intelligence, leveraging ITS, LIDAR, Wireless Sensor Networks (WSN), and 5G technologies. Their method, Bidirectional Multi-Tier IoT drone with Swarm optimization (BMTD-IoT-S), ensures safe distances between vehicles through intelligent coordination of drone swarms and vehicular networks, thereby minimizing the risk of collisions. In a similar vein, Geomes et al.[22] address the challenge of achieving collision-free flight in autonomous drones, particularly in dynamic and unpredictable environments. Through a combination of visual information from monocular cameras and Model Predictive Control (MPC), their approach enables real-time obstacle avoidance while maintaining accurate tracking and safe distances from obstacles.

III. Methodology

This section describes the proposed system and its functionalities.

A. Webots Simulation

Webots is a widely used robotics simulation software that provides a virtual environment for developing and testing robotic systems. It offers a comprehensive platform for simulating various aspects of robot behavior, including movement, sensors, and interactions with the environment. Researchers often utilize Webots to prototype and validate algorithms before implementing them on physical robots, saving time and resources in the development process.

In the context of developing a collision avoidance system for drones, researchers employed Webots simulation to create a virtual environment representative of real-world scenarios. This allowed them to design and test their collision avoidance algorithms in a controlled and repeatable manner. By simulating different flight conditions, obstacles, and drone configurations, researchers could assess the performance of their system under various circumstances and fine-tune their algorithms accordingly.

The use of Webots simulation in this study enabled researchers to develop a robust collision avoidance system without the need for costly and time-consuming physical experimentation. It provided a realistic yet safe testing environment where researchers could iterate and optimize their algorithms until achieving satisfactory results. Overall, Webots simulation played a crucial role in the development of the collision avoidance system, offering researchers a powerful tool for prototyping and validating their solutions before deployment in real-world applications.

B. Collision avoidance drone

The DJI Mavic 2 Pro, renowned for its compact design, advanced capabilities, and high-resolution camera, is seamlessly integrated into the Webots simulation environment to accurately replicate its real-world functionalities. Within this simulation framework, the DJI Mavic 2 Pro is equipped with an array of sensors and actuators, meticulously crafted to mirror its behavior in actual flight scenarios. These include essential components such as GPS, IMU, gyroscope, and motor controllers, meticulously modeled to ensure precise emulation of the drone's flight dynamics, including thrust, torque, and aerodynamics across various environmental conditions.

A pivotal enhancement in this simulation is the integration of distance sonar sensors directly onto the DJI Mavic 2 Pro. Positioned strategically at the front of the drone, these sensors deliver real-time distance measurements to nearby objects, enabling accurate obstacle detection and ensuring safe navigation within the simulated environment. By incorporating these distance sonar sensors into the simulation, researchers can develop and refine collision avoidance algorithms with heightened efficacy, leveraging the drone's ability to perceive and respond to its surroundings in real-time.

Moreover, researchers in this study have augmented the DJI Mavic 2 Pro with a sonar Distance sensor placed at the front of the drone's camera, precisely positioned with translation values of 0.07, 0, 0. This configuration situates the sensor at the top front of the drone, enhancing its obstacle detection capabilities. Table 1 showcases the lookup table (a table used for specifying the desired response curve and noise of the device) values pertinent to this sensor integration. Additionally, Figure 1 visually illustrates the placement of the sonar Distance sensor on the drone, captured in a screenshot. This integration not only amplifies the drone's perception capabilities but also underscores the meticulous attention to detail in crafting a comprehensive and realistic simulation environment within Webots.

TABLE I
LOOPUP TABLE

LoopUp Table Values		
0	2000	0
0.35	1023	0
0.85	0	0

The values in the TABLE1 means that for distance of meter 0 the sensor will return 2000 meters and with 0 noise, same goes for the rest 2 rows.

Fig. 1. DJI Mavic 2 Pro Drone with integrated Distance sensor.

C. Nodes explanation

In Webots, nodes are fundamental components of the scene graph, which is a hierarchical structure representing the objects and entities in the simulated environment. Nodes can represent various elements such as objects, sensors, actuators, lights, cameras, and more. Each node in the scene graph has specific properties and functionalities that define its behavior and interaction within the simulation.

Nodes in Webots are organized in a tree-like structure, with each node having a parent and potentially one or more children. This hierarchical arrangement allows for the organization and management of complex simulated environments. Nodes can be manipulated and controlled through the Webots API (Application Programming Interface), enabling users to create dynamic and interactive simulations.

Some common types of nodes in Webots include:

- Transform nodes: Represent the position, orientation, and scale of objects in the simulation.
- Shape nodes: Define the visual appearance and geometry of objects.
- Sensor nodes: Simulate sensors such as cameras, lidars, proximity sensors, etc., allowing robots to perceive their environment.
- Actuator nodes: Control the movement and behavior of robots and other objects.
- Light nodes: Define lighting conditions and properties within the simulated environment.
- Group nodes: Organize other nodes into logical groups for easier management and manipulation.

Nodes in Webots serve as the building blocks for creating complex and realistic simulations, providing users with the flexibility and control needed to design and test various robotics and AI algorithms in virtual environments.

D. Drone Proto

In VRML (Virtual Reality Modeling Language), `PROTO` is used to define a new node type with a specific set of fields and behaviors. It allows users to encapsulate complex objects or entities into reusable components, making it easier to create and manipulate objects within a VRML scene.

The `Mavic2Pro PROTO` defines a quadcopter drone model called "Mavic 2 PRO" with various fields like `translation`, `rotation`, `name`, `controller`, etc. This `PROTO` can be instantiated multiple times within a VRML scene with different parameters to create multiple instances of the drone.

E. Distance Sensor Node Explanation

The distance sensor is defined using the `DEF` keyword as `DISTANCE` within the `Mavic2Pro PROTO`. It is a `DistanceSensor` node, which represents a sensor capable of measuring distances to objects in the environment. The sensor is positioned at `translation 0.06 0 0`, meaning it is located 0.06 units along the x-axis from the drone's origin. It is represented visually as a small box (`Shape` with a `Box` geometry) with a size of `0.04 0.04 0.04`. The sensor type is set to "sonar", indicating that it operates based on sonar principles. It emits two rays (`numberOfRays 2`) in an aperture of `1.1` radians to detect obstacles. The sensor's lookup table defines the distance values and their corresponding ADC (Analog-to-Digital Converter) readings. Overall, this distance sensor node enables the drone to perceive its surroundings and avoid obstacles during flight simulations.

Code Description

- The code is a simplified implementation of a drone control system using Webots, a robot simulation software.
- It initializes the Webots environment and sets up various devices such as distance sensors, cameras, LEDs, motors, gyroscopes, etc.
- Constants and variables are defined for PID constants, target altitude, and time step.
- The main loop continuously runs until the simulation is terminated. Within this loop, the following actions are performed:
  - Sensor data is retrieved to determine the current state of the drone.
  - The camera is stabilized based on feedback from the gyro.
  - User input from the keyboard is processed to control the drone's movement and adjust the target altitude.
  - Obstacle avoidance is implemented using data from the distance sensor.
  - Motor inputs are computed to control the drone's movement and maintain stability.
  - The computed motor inputs are applied to the propeller motors to control the drone's movement.
- After the main loop exits, cleanup tasks are performed to disable devices and end the Webots simulation.

Algorithm Listing

Below is the code listing:

```
Constant: thrust, PID constants
Variable : target altitude
while robot is active do
    // Sensor Readings;
    Read sensor values like distance, roll, pitch,
      altitude, etc.;
    // LED Control;
    Alternate front LEDs of the drone.;
    // Camera Stabilization;
    Adjust camera motors based on gyro feedback.;
    // User Input;
    Translate keyboard input into disturbances for
      stabilization algorithm.;
    // Stabilization Algorithm;
    Compute roll, pitch, yaw, and vertical inputs using
      PID control and disturbances.;
    // Obstacle Avoidance;
    if obstacle detected then
        Adjust pitch disturbance to avoid collision.;
    end
    // Motor Actuation;
    Set motor velocities based on computed inputs and
      disturbances.;
end
```

F. Threshold Values for Distance Sensor

The threshold value used for the distance sensor is defined as `OBS_THRES` and set to 100 in the code. This threshold is used to determine if the drone is too close to an obstacle. If the distance sensor reading exceeds this threshold, the drone adjusts its behavior to avoid collision. For example, in the code provided, if the distance sensor reading (`sensor_val`) is greater than or equal to 500, the pitch disturbance is set to 0.4, indicating that the drone is too close to an obstacle and needs to avoid it.

IV. Results

The collision avoidance system developed using the Webots simulation environment demonstrates promising results in enhancing the safety and efficiency of drone operations within warehouse facilities. Through extensive simulations, the system effectively navigates drones through dynamic environments while avoiding collisions with obstacles and other drones. Key performance metrics such as obstacle density, drone speed, and environmental conditions are considered during the evaluation process.

The system showcases the following notable results:

1) **Reduced Collision Risk:** By integrating sensors and algorithms, the collision avoidance system significantly reduces the risk of collisions during drone navigation. Real-time obstacle detection and avoidance strategies ensure safe maneuvering even in cluttered environments.
2) **Enhanced Navigation Efficiency:** Drones equipped with the collision avoidance system demonstrate im-

proved navigation efficiency, effectively avoiding obstacles without compromising speed or trajectory. This leads to smoother and more reliable drone operations within warehouse facilities.

3) **Optimized Warehouse Productivity:** The implementation of the collision avoidance system contributes to overall warehouse productivity by minimizing disruptions caused by collisions or navigation errors. Drones can autonomously perform tasks such as inventory management, order picking, and logistics with greater efficiency and accuracy.

V. Conclusion

In conclusion, the development and evaluation of the drone collision avoidance system in warehouse management using the Webots simulation environment present a significant advancement in industrial robotics. The system's ability to autonomously navigate drones through dynamic environments while avoiding collisions underscores its importance in enhancing safety and efficiency within warehouse facilities.

By leveraging sensors, algorithms, and simulation technologies, the proposed system addresses critical challenges associated with drone operations in industrial settings. It offers a scalable and adaptable solution for warehouse management, enabling seamless integration of drones into existing workflows while minimizing risks and optimizing productivity.

Future research directions may include further optimization of collision avoidance algorithms, integration with advanced navigation techniques such as SLAM (Simultaneous Localization and Mapping), and validation through real-world testing scenarios. Additionally, exploring the integration of AI and machine learning algorithms for adaptive obstacle avoidance and decision-making could further enhance the system's capabilities in dynamic environments. Overall, the collision avoidance system represents a significant step towards realizing the full potential of drones in revolutionizing warehouse management practices.

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