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A Fast Warehouse Inventory Micro Aerial Vehicle System Equipped with Visual Guidance and Navigation Algorithm

H. Fahimi, A. Naghash*

Department of Aerospace Engineering, Amirkabir University of Technology, Tehran, Iran.

ABSTRACT: This paper is an attempt to integrate computer vision techniques and micro aerial vehicle guidance to design and optimize an automated mission performed by a light micro aerial vehicle such that automating the mission becomes reasonably more efficient than performing it manually. A system is provided for warehouse management using a micro aerial vehicle equipped with a front camera. Computer vision algorithms make it possible for the micro aerial vehicle to locate packages, verify the presence or absence of a specified package and list the entire warehouse inventory in a short time. An innovative method is provided to detect shelves and their packages by the camera image, which enables the system to instantly plan the shortest path for the micro aerial vehicle while performing a shelf inventory listing. Then, following the planned path completes the mission faster than conventional guidance methods. The guidance algorithm is designed such that the efficiency of automatic operations compared to human operations is significantly increased. The system is first simulated and then implemented and the test output data is provided. The tests indicate the success of the system in securing automated operations while decreasing mission time.

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1. INTRODUCTION

In recent years, there has been a remarkable increase in research related to guiding and navigating Micro Aerial Vehicles (MAVs) to provide indoor services. One of these services is MAV-aided warehouse inventory. Reviews show that the MAV systems not equipped with cameras cannot perform such missions within indoor spaces. MAV-aided inventory operations include two significant parts: package identification and guidance. In some works, guidance is done with the help of non-visual sensors (such as Ultra-Wide Band (UWB) [1] or Inertial Measurement Unit (IMU) [2]). Mostly, package identification is made using a front camera to detect visual IDs ([3,4]). Some works are fully vision-based. The MAV guidance is done using additional visible markers (such as ground markers [5]) in these works. There is a lack of guidance considerations such as path optimization to save time or energy, like in Ref. [6].

This work aims to design and implement a warehouse inventory MAV system, somehow more efficient than the related works. The significant contributions of the present system are as follows:

· The whole operation is based on a cheap MAV with minimum primary requirements.

· Operations are entirely based on a single camera. There is no reliance on other sensors.

· The empty shelf cells are detected so that the path is optimized by passing through them.

*Corresponding author's email: naghash@aut.ac.ir

2. METHODOLOGY

The problem warehouse contains several shelves lined up sequentially parallel. Several boxes, each with an ID, are randomly placed in different shelf cells. The purpose is to list all box IDs and locations. It is necessary to place colored tags at the intersection of the vertical and horizontal shelf bars. Also, the minimum distance between the shelves must be such that there is no need for the MAV to move to scan the shelf.

The MAV takes off and is positioned at the optimal viewpoint (the shortest distance where there is no need to move to observe the entire shelf). After shelf inventory, it follows the shortest path through the empty cells to get to the optimal viewpoint in front of the next shelf. This continues until the package list is completed. During the mission, the computer vision algorithm provides the list and required feedback for guidance.

2.1. Computer vision algorithm

The packages are identified by ArUco marker IDs from the OpenCV computer vision library. The shelf identification process is performed by filtering the image to visualize only the objects with the color of cell intersection tags. Shelf detection is challenging when the MAV (camera) is oriented somehow relative to the shelf facade. In such cases, to distinguish the two front and back shelves, tags with an area ratio of less than a particular size concerning the largest tag in the image are removed. We use a stair classification (Fig. 1-b) instead

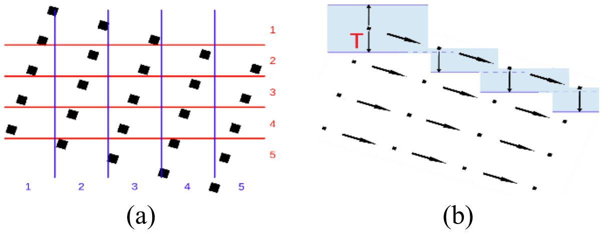


Fig. 1. (a) Normal classification and (b) Stair classification of a rotated point grid

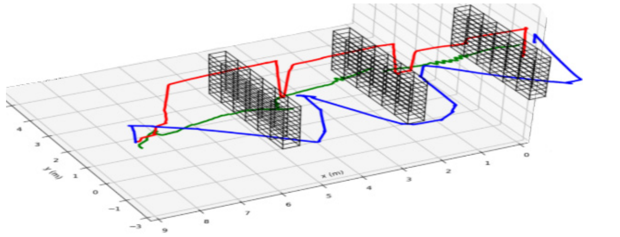


Fig. 4. A comparison between the path generated by the present guidance algorithm and the conventional guidance algorithms

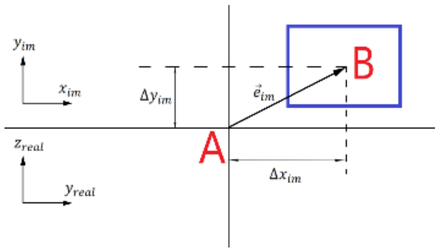


Fig. 2. The visual feedback for altitude and heading control

Table 1. Evaluation of the MAV flight time and distance caused by the present method optimal path and conventional methods

Path generation strategy	Average elapsed time	Average traveled distance
Crossing shelves	240 sec	14 m
Crossing shelf tops	300 sec	22 m
Crossing shelf sides	360 sec	28 m

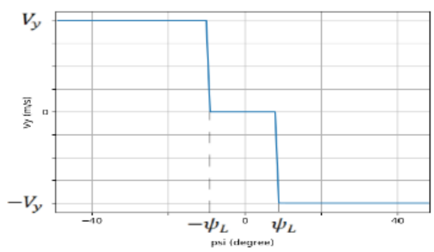


Fig. 3. *y*-direction velocity command in terms of the visually measured heading angle

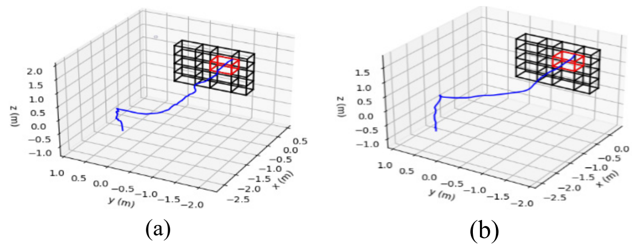


Fig. 5. The three-dimensional navigation data diagram in two different flights through the target cell (red) of the shelf (black)

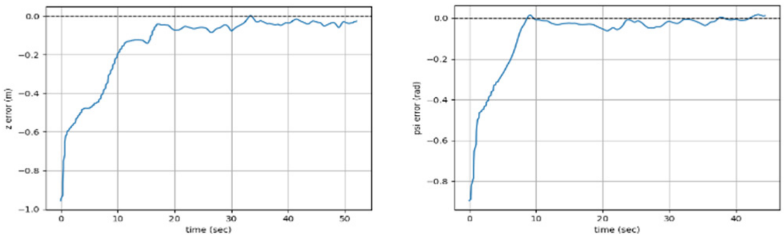
of normal classification (Fig. 1-a) to categorize the tags in rows and columns. First, a fixed threshold for the maximum allowed vertical distance between two co-row tags is found (*T* in Fig. 1-b). Then, starting from one corner, the first co-row tag is found for each tag, and it goes on like visualized in Fig. 1-(b). The same goes for column categorization.

After a shelf inventory, the closest empty cell to the next shelf's optimal viewpoint is selected. The bounding rectangle of four corner tags of this cell is tracked in the following frames using the Median Flow tracker in the OpenCV. This rectangular cross-section is where the MAV must cross. By matching the location of the target cell's corner tags in the image with the actual points (knowing the target cell dimensions), the position (transfer vector) and orientation (rotation matrix) of the camera relative to the rectangular cross-section is provided. Hence, the resulting 6 Degree of Freedom (DOF) navigation data enables us to guide the MAV to cross the shelf.

2.2. Guidance and control algorithm

In the beginning, the MAV is guided to the optimal view point by the appearance of the first fragment of the tags grid (with a known number of tags, thus known dimensions). The shelf data are recorded, and the MAV is guided to cross the target cell using the navigation data. The path must be perpendicular to the cross-section. In this way, in the last phase (close distances, where the corner tags are out of the camera field of view), the MAV is aligned with the cross-sectional center of the cell. So it moves forward at a constant speed with no other movement, and the flight is secured in terms of collision with cell margins.

The vertical position and heading angle are controlled so that the image centroid (*A* in Fig. 2) coincides with the center of the target box (*B* in Fig. 2). The lateral position must be controlled to provide a collision-free crossing with a trajectory perpendicular to the shelf. The lateral speed command is generated according to the heading angle stated in visual navigation data, with a bang-off-bang control strategy as seen in Fig. 3. Three separate Proportional–Integral–Derivative (PID) controllers are used for lateral and vertical speed and heading angle control. The longitudinal direction speed is constant.



(a) (b)

Fig. 6. The time response of the MAV (a) vertical position (b) heading angle

3. RESULTS AND DISCUSSION

Tests have been performed in both simulation and reality to evaluate the system performance.

3.1. Simulation

The system is simulated in the Gazebo - a 3D graphic simulator – with a ready-made simulated version of the Parrot AR Drone 2.0. The system's performance in the simulation is analyzed in a warehouse such as Fig. 4 and compared with two common routes: passing through the top of the shelves (red) and passing through the shelves' sides (blue). The simulation results are presented in Table 1.

3.2. Implementation

The system's ability to pass the MAV through a sample shelf was evaluated in practice. A symbolic shelf with known dimensions and mission requirements as described in section 2 is prepared. The test MAV is a DJI Tello. The flight test is initialized at 2.5 to 3.5 meters from the shelf on the ground. Designed software runs on the computer and guides the MAV via a Wi-Fi connection. Success in this experiment means recording the correct information and crossing the shelf without collision. The test is done several times, and the reliability has been acceptable. Numerical data of the MAV trajectory during two successful flights are provided in Fig. 5. The listing of the hypothetical packages on the shelf has been quite successful.

The system's time response to vertical position and heading angle control in a successful flight is presented in Fig. 6. It can be seen that the system error tends to zero, and the system is stabilized.

4. CONCLUSION

This paper presented a vision-based warehouse inventory MAV system equipped with automatic navigation and guidance. The test results illustrate the practical success of the system. The MAV passes the shortest route through the shelf with no detour, indicating the path optimality. Regarding the cost, the MAV with which the test was implemented is priced at $100. Additionally, the whole algorithm works with the input received by a single camera. Therefore, it can be said that the designed system can meet the stated three initial goals regarding the quality of mission execution.

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