Demo Abstract: Navigating Indoor: A Cost-effective Drone-based Solution

Zicong Wen
The University of Adelaide, Australia
zicong.wen@adelaide.edu.au

Wei Emma Zhang
The University of Adelaide, Australia
wei.e.zhang@adelaide.edu.au

Lipin Guo
The University of Adelaide, Australia
lipin.guo@adelaide.edu.au

Weitong Chen
The University of Adelaide, Australia
weitong.chen@adelaide.edu.au

ABSTRACT

Drone technology has made significant strides this decade, transforming industries and everyday activities with various applications. One visionary area is the integration of indoor drone systems to aid individuals in need of regular care, empowering them to live independently. This paper introduces a cost-effective drone-based indoor system and focuses on presenting our preliminary results on environment mapping. Our approach prioritises affordability and hardware-friendly technologies, ensuring accessibility. Our main contribution is the provided solution only relies on a single camera and is built upon a cheap programmable small-sized drone[1].

KEYWORDS

Drone, Indoor Mapping, Edge and Corner Detection

ACM Reference Format:
Zicong Wen, Wei Emma Zhang, Lipin Guo, and Weitong Chen. 2023. Demo Abstract: Navigating Indoor: A Cost-effective Drone-based Solution. In *The 21st ACM Conference on Embedded Networked Sensor Systems (SenSys '23), November 12–17, 2023, Istanbul, Turkiye.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3625687.3628412

1 INTRODUCTION

Automated indoor navigation is applied in retail, healthcare, manufacturing, and logistics, making indoor spaces more accessible, efficient, and interconnected. Indoor mapping and localization is the field of technology as the cornerstone of indoor navigation that builds upon various technologies from electrical engineering and computer science. The main tasks are to create detailed maps and accurately determine the location of individuals or objects within the indoor setting. In the recent decade, due to the proliferation of smart devices and the advancements of wireless communication technologies, indoor mapping and localization enjoy a wider range of applications to help build smart environments [4].

[1]The demonstration of the system is provided as a YouTube video: https://youtu.be/EAQMOytuZqQ

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than the author(s) must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org.
SenSys '23, November 12–17, 2023, Istanbul, Turkiye
© 2023 Copyright held by the owner/author(s). Publication rights licensed to ACM.
ACM ISBN 979-8-4007-0414-7/23/11…$15.00
https://doi.org/10.1145/3625687.3628412

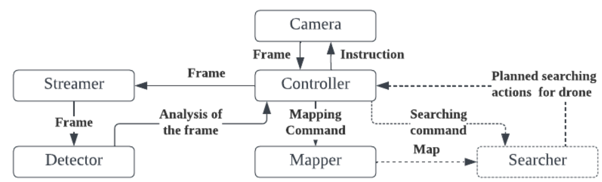

Figure 1: System modules.

Drone-based research is transforming data collection and analysis in various scientific fields. Drones provide researchers with unprecedented access to remote and hard-to-reach areas, however is rarely explored under small-scale indoor systems. Existing works either provide a vision for indoor drone-based systems [3] or rely on expensive (but more functional) drones [2] that impede the adoption from customers. In this work, we present an innovative indoor drone assistance system solution that is built upon a low-cost, ultra-light drone, DJI Tello Education. The system is capable of performing simple environment mapping (implemented) and self-localization (ongoing) by only using a single camera pointing downwards. The computer vision techniques applied are computationally efficient and easy to deploy. Through this work, we demonstrate that it is feasible to utilize uncomplicated and budget-friendly technology to build a comprehensive system. This work could be the first step toward the research and development of low-cost indoor drone-based home assistance systems.

2 THE SYSTEM

2.1 Hardware

The camera captures the frames in real-time and uses the ESP32 module to transmit the frames to the computer using the Local Area Network (LAN) that is created by a Wi-Fi modem. After the computer processes the frame, it gives instructions to the drone via LAN. When the drone receives the instruction, it travels to its destination with the camera module strapped on the bottom.

More specifically, we used an ESP32-WROVER camera kit which weighs about 5 Kg and cost approximately AUD $100, an ultra-light and ultra-low-cost DJI Tello Education version that approximately weighs 80 g and costs AUD $219, TP-Link Archer C1200 to form LAN and personal computer to execute the programs.

2.2 Functional Modules

The system consists of four functional modules **Detector**, **Mapper**, **Streamer**, **Searcher** and **Controller**, as shown in Fig. 1. The implementation of the Searcher module is our next step. Here, we introduce the mapping process enabled by the developed modules.
Controller. The Controller controls the whole process of mapping. The Controller receives and analyses the images from the Detector, and passes instructions to the drone and the Mapper. Fig. 2 shows the process. Assume that the drone is initially located at a random spot and could head in any direction (Fig. 2a). In this status, the Controller controls the process of exploring the environment until it finds the first edge or corner (Fig. 2b). After that, the Controller rotates the drone while keeping the direction of the drone perpendicular to the edges until the drone is aligned with the detected edge and corners (by the Detector), the controller will initiate the Mapper and instruct the drone to follow the edges and corners when travelling through the room. While the drone is travelling, the Controller will instruct the Mapper to drop an "anchor" after the frame has been processed (Fig. 2c). After four corners of a room are obtained by the Mapper, the mapping will stop as well as the drone's movement. An *occupancy grid map*, which contains no values except the boundary that is filled with -1, will then be constructed (Fig. 2d) and the constructed map will be sent to the Searcher, to initiate the searching process (Fig. 2e).
Detector. The main detect function combines the corner and edge detection functions to identify features in the image and returns potential analysis, such as actions (i.e., what drone should take for the next steps), steps (i.e., the magnitude of the drone should execute the actions), and events (i.e., the situation the drone is encountering). We used the Canny edge detection [1] and Hough Line Transform techniques which provide information about the drone's posture above an edge. We utilised the Harris Corner Detection algorithm [5] to find corner coordinates in the input image. We applied a clustering method to identify the most prominent corner among the detected candidates.
Mapper. The Mapper is used to construct the occupancy grid map. While the drone is moving around the room, an "anchor" is dropped every time a new frame is received. The map is constructed based on the number of anchors collected for each edge, with extra one-layer padding which is filled with "-1" in each direction to denote the boundaries of the environment.
Streamer. This module provides an interface to display the video stream from the ESP32 module in a Pygame window.
Searcher The searcher is designed to explore the undiscovered area of the environment to seek items, which will be our next step.

3 EMPIRICAL STUDIES

Inspired by Absolute Trajectory Error (ATE), which is simple but effective for a rectangular-shaped environment, we develop a metric to measure the similarity of the real map and the constructed map. Assume the occupancy map A has shape $[M, N]$, our metric compares the ratio of the number of rows and columns of the occupancy map. Eq. (1) and Eq. (2) show the methods of transforming the occupancy grid and the real-world environment to the same dimension respectively.

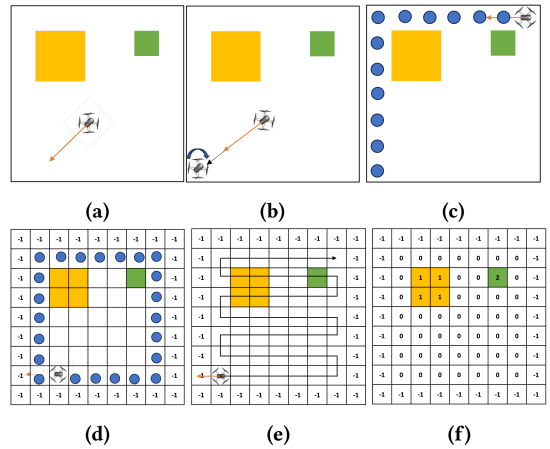

Figure 2: The mapping process. The black arrow represents the drone's path, the red arrow represents the drone's facing direction, the blue points indicate the *anchors*, and -1 denotes the wall. The yellow and green squares are the location of the items. The searcher module is designed to estimate the coordinates of these squares.

$$f(R_{constructed}) = f(A_{MN}) = \frac{M}{N} \tag{1}$$

$$g(R_{real}) = g(width, length) = \frac{width}{length} \tag{2}$$

The metric is defined as the root mean square from the error matrices:

$$Ratio_{RMSE} = (\frac{1}{n}\sum_{i=1}^{n} ||f_{constructed_i} - g_{real_i}||)^2 \tag{3}$$

Using our metric to evaluate the system's performance yields an average score of 0.827 for five testing videos tested on the system. Here, numbers close to 1 denote the best performance, while numbers close to 0 denote bad performance.

4 CONCLUSION AND FUTURE WORKS

In this paper, we have presented a cost-effective drone-based navigation system. We provided our preliminary results on building the system, creating the map, and performing searching. The system's robustness to the environment and real-time responsiveness is under work to be improved. We will also further increase the accuracy of the mapping in our follow-up works.

REFERENCES

[1] John Canny. 1986. A Computational Approach to Edge Detection. *PAMI* 6 (1986), 679–698.
[2] Abedi et al. 2022. Non-cooperative wi-fi localization & its privacy implications. In *MobiCom 2022.* 570–582.
[3] Xia et al. 2021. A Drone-based System for Intelligent and Autonomous Homes. In *SenSys 2021.* 349–350.
[4] Zafari et al. 2019. A Survey of Indoor Localization Systems and Technologies. *IEEE Commun. Surv. Tutorials* 21, 3 (2019), 2568–2599.
[5] C. Harris and M. Stephens. 1988. A Combined Corner and Edge Detector. In *Proceedings of the 4th Alvey Vision Conference.* 147–151.