Aerial robotic operations

Citation for published version (APA):

Gou, Y. (2024). *Aerial robotic operations: multi-environment cooperative inspection & construction crack autonomous repair*. [Doctoral Thesis, Maastricht University]. Maastricht University. https://doi.org/10.26481/dis.20240115yg

Document status and date:
Published: 01/01/2024

DOI:
10.26481/dis.20240115yg

Document Version:
Publisher's PDF, also known as Version of record

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:

www.umlib.nl/taverne-license

Take down policy
If you believe that this document breaches copyright please contact us at:

repository@maastrichtuniversity.nl

providing details and we will investigate your claim.

Download date: 15 May. 2024

AERIAL ROBOTIC OPERATIONS: MULTI-ENVIRONMENT COOPERATIVE INSPECTION & CONSTRUCTION CRACK AUTONOMOUS REPAIR

YIYONG GOU

Summary

Aerial robots are widely sought after in a large number of applications. A prominent example of such applications is disaster management, where robots can play crucial and innovative roles in post-disaster rescue, search, and manipulation to offer a safe and fast response. Research described in this dissertation concentrates on two key aspects of this application, namely, multi-environment cooperative inspection (Part I) and construction crack autonomous repair (Part II). Part I is on building an inspection framework using two aerial robots of different sizes. Part II is on developing a construction crack autonomous repair scheme using a Delta manipulator and an aerial platform. Among the techniques related to the described research are robotic hardware design, localization, flight control design, object detection, navigation, and robotic manipulation. They are all employed to achieve the main research objectives of this dissertation.

Part I consists of three chapters. Firstly, in Chapter 3 an aerial carrier attached with an anchoring mechanism for locking or releasing a companion UAV is presented. Moreover, a docking board with a Fractal marker is mounted to our aerial carrier. Regarding the companion UAV design, a lightweight and low-cost DJI UAV Tello is modified. We convert DJI UAV Tello's original forward camera to a downward camera, and also design a foot extender to acquire a locking mechanism. Our developed aerial carrier has abilities of self-localization, environment mapping, and stable flight. With these abilities and its anchoring function for the companion UAV, This aerial carrier provides a platform for our companion UAV transportation. In Chapter 4, we use the same companion UAV. The docking board with a Fractal marker in Chapter 3 is modified into a cross-configuration docking board with a Fractal maker in the center and four ArUco markers in four directions. Moreover, a visual error metric approach is used to detect this docking board along with a Kalman filter based tracking method. This tracking method is to deal with issues such as measurement noise or camera temporary freeze. With the assistance of our designed height-dependent PID controller for our companion UAV, the companion UAV can successfully conduct aerial in-flight docking on the aerial carrier. Compared to previous aerial in-flight docking research, our research highlights that our aerial robots operate without any external localization system. This implies that this work can be applied practically in an environment that lacks GPS or an external tracking system. In Chapter 5, an approach to cooperative inspection of a dark hole using an aerial carrier and a companion UAV is presented. The companion UAV is modified based on that companion UAV in Chapter 4. A ToF module and a micro-controller to sense obstacles are added. Moreover, a red LED, a white LED, and a set of modified foot extenders are mounted to this companion UAV. Regarding the aerial carrier, it is the same as that in Chapter 4. The aerial carrier provides assistive vision for our companion UAV. The companion UAV localization is

based on the RGB and depth information provided by the aerial carrier. Moreover, the hole entrance localization is based on the depth information that is also provided by the aerial carrier. During the hole inspection, the companion UAV navigates based on three-direction obstacle distance information. In addition, the aerial in-flight docking procedure in Chapter 4 is also implemented to enable our companion UAV to dock on the aerial carrier after the companion UAV inspecting the dark hole. The experiments of this multi-environment cooperative inspection are tested in the University Sports Center and our robotics lab. These experiments illustrate that our proposed multi-environment cooperative inspection approach is a solid basis for further applications. Overall, this is the first time to inspect a dark hole with this new aerial companion style using two aerial robots of different sizes. Moreover, the proposed cooperation style can be extended towards the use of other types of robots.

Part II, consisting of Chapter 6, deals with construction crack autonomous repair. Specifically, this chapter describes the integration of an aerial platform (similar to the one presented in Chapter 3) and a Delta manipulator. In terms of software design, vision based technology combined with aerial robotic techniques is applied to crack repair. The first step for crack repair is to localize cracks using a high-resolution RGB camera. This crack localization is achieved with the assistance of deep learning based segmentation and the distance data obtained from a ToF sensor. Given a crack 3D position, the entire flight system including a position controller, an attitude controller, and a navigation module, is used to guide the aerial system to reach the crack center. In order to undertake the repair procedure, an nozzle movement trajectory is generated using a crack filling trajectory generator. Moreover, a cement extruder with a speed controller is exploited according to the generated nozzle movement trajectory. Real world experiments demonstrate that this approach is useful in our lab environment. This approach can be selected as a primary method for construction crack repair in the future.

We have achieved multi-environment cooperative inspection and construction crack autonomous repair using our developed systems. Subject to this cooperative inspection, the current solution still relies on ground computation to guide and control the companion UAV and to conduct the detection of the ArUco-Fractal marker. Future work could aim at improving the companion UAV's onboard computation abilities to achieve its full onboard autonomy. In terms of construction crack autonomous repair, the computation related to deep leaning based segmentation algorithm is still offline. Future research could thus aim at a crack detection solution achieved through onboard computation. Throughout this dissertation, the most important lesson we learned is that an entire autonomous robotic system necessitates a trade-off between the robotic frame design, onboard sensors, onboard/offline computation, software compatibility, and energy consumption.