Aerial robotic operations

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IMPACT PARAGRAPH

In this impact paragraph, a reflection is presented on the scientific impact on the research described in this dissertation. This is done by addressing the drafted four impact questions in the Maastricht University Promotion Regulations (Article 12, Paragraph 8, entry into force on 1 February 2023).

> **Research**
>
> What is the main purpose of the research described in the thesis and what are the main results and conclusions?

Answer:

Based on the main research objectives presented in Chapter 1, conclusively the main purpose of our research can be summarized as developing two aerial systems to conduct a cooperative inspection task in a multi-environment scenario and to conduct construction crack autonomous repair, respectively; moreover, these two aerial systems should be versatile and reconfigurable aerial robotic systems.

One of the two main objectives of research described in this dissertation is to develop, to demonstrate, and to explore aerial robots that cooperate to reach and to inspect areas that require inspection. We are especially interested in combining aerial robots with different properties and to explore approaches to let these aerial robots work together. Given the challenges of integrating powerful computing hardware required for computer vision and flight control into aerial robots with limited payloads, the presented research aims to explore how computational resources, control, and computer vision can be distributed and shared among different aerial robots. The second main objective of the presented research is to develop, to demonstrate, and to explore an aerial system that can autonomously identify cracks in constructions and repair these cracks. To meet the first objective, we developed the hardware of two aerial robots and the required software. The two developed aerial robots are the aerial carrier and the companion UAV. The larger aerial robot, the aerial carrier, is capable of transporting the small aerial robot, the companion UAV. The two developed aerial robots are described in Chapter 3. The aerial carrier can further be reconfigured to also perform crack detection and repair. The described research demonstrates how the aerial carrier and companion UAV can cooperate to achieve semi-automated inspections. A controller, hardware, and software have been developed to allow the companion UAV to dock on the aerial carrier while the aerial carrier is flying. This work is presented in Chapter 4. In Chapter 5, we describe the achieved cooperation between the companion UAV and aerial carrier for the inspection of a narrow dark hole that the aerial carrier cannot enter. The work achieves a true cooperation between the two aerial robots because the companion UAV is too small to carry all required hardware for autonomous navigation and thus it must make use of the sensors and computation resources onboard of the aerial carrier to identify and fly into a dark hole and to safely return to the aerial carrier. Chapter 6 describes the developed hardware, chosen computer vision approach, and software to enable an aerial system to autonomously identify and fill cracks in constructions. Overall, the research aims to provide and achieve proofs of concept in form of research demonstrations that are being carried out inside lab environments. Further work is required to achieve robust solutions that can be operated to assist in finding people in need of support and to autonomously inspect and repair buildings.

Relevance

What is the (potential) contribution of the results of this research to science, and if applicable to societal sectors and societal challenges?

Answer:

The techniques presented in this dissertation are relevant to a wide audience. We make contributions to the scientific fields of robotics, control, and artificial intelligence (in particular in multi-agent systems and computer vision) contributing methods, software, and robotic hardware developments. For society, the work is particularly relevant as this dissertation develops and explores solutions for post-disaster management. After a disaster, a fast response is paramount. To save as many lives as possible after a disaster, one must find as many people in need of help as quickly as possible. However, currently after major incidents such as earthquakes, it can take days to search a large area and to find people in need of help. In addition, post-disaster responders often put their own life at risk while searching for people in damaged buildings. This is why autonomous aerial robots developed in this dissertation for exploring unstructured environments including narrow spaces and a dark hole are urgently required tools. The hope shared by us and others is that one day large groups of these aerial robots can perform a first search for people and map areas and buildings after a disaster to fine people in need of help quicker and to make the work of early responders easier and safer. These aerial robots are also relevant for the inspection of constructions where regular checks are required to keep critical infrastructure such as building safety. Overall, this dissertation contributes proofs of concept in form of robotic demonstrations. Further work must be invested to create the robust solutions required for safe post-disaster management, inspection and repair of complex buildings. In more detail:

- In Chapter 3, we present the hardware and software of an aerial carrier capable of carrying smaller UAVs for exploring unstructured environments. A widely applicable flight stabilization and control approach is presented that enables aerial robots to navigate through buildings. Such flight stabilization is particularly challenging as inside buildings where no GPS is available and an aerial robot must stabilize its flight in the presence of low-texture walls and ceilings. Thus, the approach is useful for a variety of applications where drones must operate indoors including logistics centers, manufacturing areas, or greenhouses.

- A docking platform has been developed to enable an aerial carrier carrying a companion UAV. The docking platform has been equipped with visual markers of different sizes and an approach has been developed so that the companion UAV can dock on the aerial carrier without the need of human intervention. We successfully demonstrated that such a docking scheme can be also possible when both the aerial carrier and the companion UAV are flying (Chapter 4). This is particularly challenging as the aerial carrier generates considerable turbulences that the companion UAV must deal with to dock safely on the aerial carrier.

- The developed vision and control approaches are widely applicable such as in industrial and space exploration applications where objects must be tracked. In Chapter 5, we demonstrated how the aerial carrier and the companion UAV can cooperate to detect objects and inspect small areas that the aerial carrier cannot reach. A true cooperation of the two aerial robots is presented where the aerial carrier carries most of the infrastructure required for autonomous operation.

- In Chapter 6, we present an aerial system capable of autonomously detecting cracks in constructions. A mechanism and the required methods have been developed to enable the drone to fill these cracks with a cement-style material. Both the computer vision approaches to detect small damages such as cracks and the approach to determine how to best repair the cracks are widely applicable.

Target group

To whom are the research findings interesting and/or relevant? And why?

Answer:

The presented work is relevant to researchers working on autonomous flying robots as well as anyone involved in post-disaster management and in the maintenance of infrastructure such as buildings. The reason why researchers working on autonomous flying robots are interested in our work is that probably they can be inspired by the operational style of cooperation of aerial robots in different conditions. The presented work aims to make post-disaster management where often large areas must be searched and a fast response is paramount to save as many lives as possible in an easy and fast way. Autonomous aerial platforms in the future hopefully can be used to help finding people in need of rescue e.g. after an earthquake. This has the potential to save lives. We demonstrated proofs of concept for the autonomous detection and repair of cracks in constructions. Given the large number of buildings and other constructions that must be periodically inspected and maintained to remain safe, this work is relevant for the general public, construction and maintenance companies.

There are three reasons why people involved in post-disaster management are interested in our research findings, especially in multi-environment cooperative inspection. Firstly, after disasters, urgent rescue of people has highest priority and post-disaster managers need to organize fast response and decision on how to conduct recuse. For example, when an earthquake happens, rescue response should be conducted as quickly as possible, but it is fairly dangerous and risky for humans to enter the earthquake area because earthquake aftershocks may occur. In our research, we developed an aerial carrier. This aerial robot might be modified to have the potential to assist humans in inspection missions in the future. Secondly, when an earthquake happens, the aerial carrier in our research can be used to enter the earthquake area quickly, and the companion UAV in our research can be further developed or modified with life detection sensors. In this way, the modified companion UAV can be employed to enter a small and dark zone to inspect and find survivors because this small zone is required to be inspect using this kind of robot with a small size rather than the aerial carrier. Thirdly, after disasters, normally the operational area is large and complex, so cooperation between robots is one solution. In our research, the companion style between the aerial carrier and the companion UAV can be selected as one option of post-disaster management.

For people involved in the maintenance of infrastructure, they are also interested in our research findings, especially in construction crack autonomous repair. There are two reasons. (1) Construction cracks can occur after disasters such as an earthquake. Normally these cracks can be repaired by humans and reach these crack repair sites by humans. If the building crack repair sites are difficult and dangerous for humans to reach, the aerial system developed in our research can be an option for building crack repair. Moreover, it can be modified with an aerial platform with more payload and longer endurance. (2) Besides the solution using an aerial system to repair construction cracks, the method of detect cracks in our research is also attractive for people involved in the maintenance of infrastructure. The learning based detection method can also used for detect other construction objects.

Activity

In what way can these target groups be involved and informed about the research findings so that the knowledge gained can be used in the future?

Answer:

The presented work is and will be disseminated through scientific publications and demonstrations to the public. Part of the work has already been published in the form of a conference article. Additional papers are in preparation. We demonstrated the developed robotic applications at various occasions.