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Communication and Cooperation Strategies for Aerial Robotic Systems

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Kurzfassung

In den letzten Jahren hat der Einsatz von robotischen Systemen in zivilen Anwendungsfeldern stark zugenommen. Insbesondere kleine unbemannte Flugroboter, auch *Unmanned Aerial Vehicles (UAVs)* genannt, werden zunehmend durch Rettungskräfte zur Unterstützung in Katastrophenszenarien angefordert. Um die Einsetzbarkeit dieser Flugsysteme weiter zu verbessern und Rettungskräfte zu entlasten, stellen sich Herausforderungen hinsichtlich der zuverlässigen Vernetzung und Automatisierung des Flugbetriebs. Aufgrund von Ressourcenbeschränkungen kleiner Fluggeräte beinhalten zukunftsweisende Konzepte den Einsatz von kooperierenden Multirobotersystemen. Voraussetzung für den Betrieb kooperierender UAVs sind zuverlässige Kommunikations- und Mobilitätsstrategien, die sowohl die Eigenschaften der eingesetzten Kommunikationstechnologien als auch die Mobilitätsfähigkeiten der Roboter berücksichtigen.

Gegenstand der Forschung in dieser Dissertation sind neuartige Mobilitätsstrategien und Kollaborationskonzepte, die auf Basis innovativer Kommunikationslösungen die Zusammenarbeit heterogener Roboterschwärme ermöglichen. Der innovative Mobilitätsansatz *Communication-Aware Potential Fields (CAPF)* basiert auf virtuellen Potentialfeldern und berechnet anziehende und abstoßende Kräfte in Abhängigkeit von bestimmten Kommunikationsleistungsindikatoren. In Kombination mit einem verteilten Rollenkonzept können einzelne Roboter des Schwarms Verhalten und Funktion bedarfsgerecht anpassen. Der ganzheitliche Systemansatz vereint verschiedene essentielle Aspekte für die Zusammenarbeit agentenbasierter Systeme. Hierzu zählen effiziente Datenstrukturen, zuverlässige Kommunikationsstrategien sowie Methoden zur verteilten Entscheidungsfindung.

Der hohe Reifegrad der entwickelten Lösungen konnte durch eine innovative Entwicklungsmethode, die aus modellbasierten, Software-in-the-Loop sowie Hardware-in-the-Loop Simulationen besteht, erreicht werden. Kernaspekte dieser Arbeit wurden erfolgreich in der Praxis durch Flugexperimente demonstriert. Die Forschungsergebnisse wurden in zahlreichen wissenschaftlichen Veröffentlichungen auf internationalen Konferenzen und in Fachzeitschriften diskutiert und mit dem ITG Preis 2013 ausgezeichnet. Mit den erzielten Ergebnissen wird es künftig möglich sein, durch kommunikationssensitive Mobilitätsstrategien eine zuverlässige Datenkommunikation für die Steuerung kooperierender UAV-Systeme bereitzustellen und so eine wesentliche Voraussetzung für den sicheren Betrieb unbemannter Systeme zu erfüllen.

Abstract

The utilization of robotic systems in civil applications rapidly increased during the past years. Especially small *Unmanned Aerial Vehicles (UAVs)* are demanded by rescue forces to assist in disaster situations. In order to exploit the full potential of the unmanned systems, the requirements regarding mission complexity and autonomy increase. To overcome the resource limitations of small platforms, trend-setting concepts include cooperating multi-robot systems. Essential for successful cooperation are reliable communication and mobility strategies, which consider the characteristics of the applied communication technologies as well as the mobility capabilities of the individual robotic systems.

The research in this thesis addresses novel mobility strategies and concepts, which allow the collaboration of heterogeneous robotic swarms, based on innovative communication solutions. The holistic system approach considers a variety of essential aspects to enable the collaboration of agent-based systems. Key elements are efficient data structures, reliable communication strategies and methods for distributed decision-making.

The main research of this work focuses on communication sensitive mobility strategies and a role-based collaboration concept. The developed solutions address the often competing performance indicators spatial distribution of the sensor equipped robots and their communication performance. The later includes inter-agent as well as agent to end user communication. The innovative mobility strategy *Communication-Aware Potential Fields (CAPF)* is based on virtual potential fields and calculates attracting and repelling forces depending on specific communication performance indicators. In combination with the distributed role-based behavior, the individual robots are able to change their behavior and function within the swarm. By these means, they can function as on-demand relays to enable reliable communication links over large distances.

Essential parts of this research have been successfully demonstrated in real flight experiments within the scope of application driven scenarios. The results have been discussed in numerous publications on international well-respected conferences and journals. Significant parts of his research have been recognized with the VDE ITG 2013 literature award. In the future, the results of this work and especially the communication-aware mobility behaviors, enable reliable communication for command and control of cooperating UAV systems and thus contribute to fulfill an important requirement for the safe operation of UAVs.

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