Abstract

Unmanned Aerial Systems (UAS) have attracted a great deal of attention in recent years. UAS Autonomous Navigation is often split into four main tasks: Perception, Localization, Motion Planning and Motion Control.

This Ph.D. dissertation focuses on two of those tasks: Perception and Motion Planning, specifically in the context of the UAS.

The first part of the thesis focuses on perception. We investigate the design characteristics that influence the quality of the 3D environment modelling generated by a vision system on-board a UAS, including the camera design and configuration in addition to the flight plan parameters (speed and altitude). The 3D environment model richness and accuracy were used as quality indicators. We present design scheme highlighting a method to navigate the trade-offs during the design phase, grouping the design factors into requirement parameters, selection parameters and configuration, and we further map the design factors' inter-dependencies.

Moreover, we further analyse the effect of geo-tags uncertainty on the quality of the 3D environment model. ASONY ILCE-QX1L camera with 20.1MP was utilized on-board a UAS capturing images while descending and ascending in altitude range of 60 - 20 m. We evaluate the use of two different GPS data sets as initials for the camera extrinsic parameters in order to determine their accuracy. The design trade-offs between the various camera parameters and the flight plan under specific requirements like the final object resolution, the UAS speed and the required images' overlap is evaluated. The inter-dependencies and relations between these parameters and the number of quality matches are mapped and a structured computation and trade-off workflow was recommended for terrestrial mapping applications.

Finally, an industrial solution for a challenging object recognition, localization and assembly supervision is implemented and evaluated. Using an FPGA programmable industrial camera, the developed solution enables the detection and localization of the target parts, and supervision over the of the parts' feeding, conveying and heuristic orientation manipulation system. The vision system is further integrated with a FANUC industrial robotic arm, which is used to perform the pick-and place operations. The final solution is successfully implemented in a manufacturing facility resulting in processing time of less than 200ms between image capture and the declaration of the found parts, while complying with the reliability, robustness and processing time defined by the application. The solution developed can be useful for UAS perception, it enables fast object detection and localization with minimal computational cost using images processing techniques.

The second part of the thesis focuses on Motion Planning. We develop a novel kinodynamic sampling-based motion planning algorithm called MP-RRT$^{\#}$, which builds on the existing RRT$^{\#}$ by augmenting it with a Model Predictive Control method used to compute the optimal trajectory for UAS. The use of the MPC ensures the feasibility and applicability of the resulting trajectory, as both the obstacles constraints (which restrict the feasible states to the free space) and the vehicle constraints (which limit the control input constraints) are taken into consideration by the MPC during the design process. Similar to other RRT-based algorithms, MP-RRT$^{\#}$ explores the map constructing an asymptotically optimal graph. In each iteration the graph is extended with a new vertex in the reference state of the UAS. Then, a forward simulation is performed using a Model Predictive Control strategy to evaluate the motion between two adjacent vertices, and a trajectory in the state space is computed. As a result, the MP-RRT$^{\#}$ algorithm eventually generates a feasible trajectory for the UAS satisfying dynamic constraints. Simulation results obtained with a simulated drone controlled with the PX4 autopilot corroborate the validity of the MP-RRT$^{\#}$ approach.