Embedded model predictive control technique for grasping of objects with unknown weight by team of MAVs

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I. Extended Abstract

An embedded system designed for optimal control of a Micro Aerial Vehicle (MAV) or a pair of MAVs during the task of autonomous grasping of a static or dynamic object with unknown weight in the challenging outdoor environment is presented in this paper. The motivation of the proposed work is to achieve a stable and robust behavior of the system using the Model Predictive Control (MPC) technique with model adaptation that responses to changes in the total mass after grasping objects that are heavy relatively to the mass of the MAV (the additional payload represents tens of percents of the total mass of the MAV). The unknown weight of objects being grasped is one of the biggest issues in the task of autonomous objects collecting by MAVs since the very precise knowledge of the overall mass (in a precision of grams) of the system is crucial for proper setting of all state-of-the-art MAV controllers. Therefore, this issue is even more visible if MAV closed-loop control techniques are applied for object grasping than in the task of manipulation by arms of ground robots or by humanoid robots, where this problem is frequently discussed. Our particular target scenario is motivated by the third challenge of the MBZIRC competition, where our team (Czech Technical University in Prague, University of Pennsylvania and University of Lincoln; for details see `http://mrs.felk.cvut.cz/projects/mbzirc`) was selected for supported participation. In this challenge, a group of three MAVs has to search an outdoor arena for various static and moving color objects, then pick them and move them into a dedicated area. In addition, few large objects will require a collaboration between two or more MAVs to pick and place them. The key challenge in this task is the precisely coordinated flying in a compact formation while grasping the object. Moreover, the challenging outdoor desert environment in UAE, Abu Dhabi requires designing a robust solution of the autonomous grasping task, which dramatically differs from techniques usable in laboratory conditions.

The onboard robust model predictive controller developed at CTU (for the grasping, we use a modified version of an embedded MPC control scheme, which was presented by our team in [1]) may adaptively change the MAV model and controller parameters using a state estimator and Kalman filtering of onboard data. See a record from tests of the ability of the system to compensate external disturbances in `https://youtu.be/JvA62F7lUXQ`. The significant change of the model during the grasping of heavy objects (heavy relatively to the MAV weight) can be fully autonomously incorporated into the controller by observation of differences between the estimated states of the system and states achieved by applying the control inputs that are obtained by the MPC with the current model. In the next control steps, the model is iteratively altered to reduce differences between the estimated and achieved states. With this approach, we may close the loop during the grasping in a similar way as it is often done in the perception-action closed-loop in grasping by robotic arms. See a record from tests of model disturbances by adding a payload during flight in `https://youtu.be/hvOueLvYGSc`, where no information about the weight of the objects was used.

Another, more informed approach is to identify a set of MAV models for each of the various objects that can be carried in the particular application and if required also for different possibilities of grasping. For example objects of two different shapes and two different weights may occur in the MBZIRC challenge and different positions of the manipulator carrying the object can be preferred. The variation in the position of the grasped object relatively to the MAV significantly changes the center of mass of the MAV, which influences controller performance even more than the change of the total mass caused by adding the additional payload during the manipulating with the objects.

The advantage of the non-informed approach is a higher robustness to a variation of the height of the grasped objects and uncertainty in the determination of the position of the payload after its grasping. Mainly the second source of uncertainty that influences the precise identification of the model required for the MPC method occurs if solving the grasping problem specified in the MBZIRC challenge, where a magnetic gripper is used to pick up and release the objects. It is difficult to achieve a precise attaching of the metal objects of different cylindrical or rectangular shapes to the metal plate of the gripper.

On the other hand, the time period with decreased performance of the system during adaptation to the new model is significantly shorter in the informed approach, if the new system consisting of the MAV and the attached object is identified perfectly in advance of the mission. Tests in real world environment have shown that a combination of these two approaches, whenever it is possible to guess on properties of the gripping objects, provides a promising way of fast autonomous grasping by MAVs (see a video of the preliminary tests of the

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grasping task in https://www.youtube.com/watch?v=y8IKiQf6k8w&feature=youtu.be). Note that in these initial tests the system was not fully autonomous and that a predefined position of the object was given. The purpose of these tasks was to test the response of the controller on change of the MAV weight and change of position of its center of mass after object grasping and its release.

The iterative adaptation of the model being used in our embedded MPC solution enables to respond to changing environmental conditions (the wind, air flow from propellers of neighboring MAVs, etc.), while the knowledge of the identified model of the *MAV-payload* system speeds up the adaptation process. Moreover, the numerical simulations and experiments with MAV platforms have shown that due to the state feedback of MPC and the employed adaptability, the MAV achieves a robust and stable behavior even if the grasped object differs from the expectation (for example a different shape of the object is identified by a vision system, and therefore its different weight is expected). Beyond these experimental observations, it can be theoretically shown based on Lyapunov stability analyses that the incorrectly identified model of the MAV cannot destabilize the system if it is stable for all models identified for the particular systems prior the mission. This is important also in a case of a failure of the gripping task, where the identified model of the *MAV-payload* system is incorrectly used for control the MAV without the payload.

Our achievements in preparation for the MBZIRC competition are summarized in the video https://youtu.be/JYXeUrkN_cU and in a popular version of the video for Czech news https://youtu.be/vU-iHBr_dEU (experiments related to the grasping tasks are in the second half of the videos). In a case of a sufficient space availability in the IROS workshop location, we may demonstrate the possibility of autonomous object grasping via MPC visual servoing in a live demo and show the latest achievements towards the MBZIRC competition.

II. Work in progress and future work

The most challenging task of the competition is the cooperative object carrying, since it requires very precise control of MAVs flying in small relative distances, compensation of air-flow effect of neighboring vehicles, precise estimation of relative distance between MAVs, and mainly the coupling of controllers during the cooperative grasping and consequent conjunct flight. It requires simultaneous adaptation of MAV models, if using MPC. For coordination of a pair of MAVs and their stabilization in a formation with very small relative distance, we built on our achievements in control and stabilization of compact MAV formations [2]. The precise relative distance between MAVs during their approaching to the grasping object is obtained by onboard visual relative localization [3], [4], which was developed within our team for stabilization of MAV swarms [5], [6], [7], [8] and heterogeneous UGV-MAV teams [9], [10], [11], [9] in real-world GPS-denied conditions. Cooperative flight of the MAV pair carrying the large object will be realized by coupling of controllers of both MAVs based on results achieved by our team members from UPENN [12], [13], [14], [15]. All these methods consider the system dynamics and show that the system is differentially flat to plan dynamically feasible trajectories. The key challenge, which we are facing now, is to adapt these methods for deployment in the challenging outdoor conditions (without motion capture systems) using the visual relative localization in control feedback, and integrate them into the embedded MPC controller. For preliminary results see end of the video at https://youtu.be/JYXeUrkN_cU with results captured during our experimental camp in June, 2016. The latest results obtained during the next experimental camp scheduled on September will be also presented during the workshop.

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